Effects of Stereoscopic 3D Digital Radar Displays on Air Traffic Controller Performance

THESIS

Jason G. Russi, Technical Sergeant, USAF

AFIT-ENV-13-M-24

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

DISTRIBUTION STATEMENT A
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED

AFIT-ENV-13-M-24

The views expressed in this thesis are those of the author and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the United States Government. This material is declared a work of the United States Government and is not subject to copyright protection in the United States.

AFIT-ENV-13-M-24

Effects of Stereoscopic 3D Digital Radar Displays on Air Traffic Controller Performance

THESIS

Presented to the Faculty

Department of Systems Engineering and Engineering Management

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Information Resource Management

Jason G. Russi

Technical Sergeant, USAF

March 2012

DISTRIBUTION STATEMENT A
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED

AFIT-ENV-13-M-24

Effects of Stereoscopic 3D Digital Radar Displays on Air Traffic Controller Performance

Jason G. Russi
Technical Sergeant, USAF

Approved:

______________________________	__________
Brent T. Langhals, Lt Col, USAF (Chairman)	Date
______________________________	__________
Michael E. Miller, PhD (Member)	Date
______________________________	__________
Paul R. Havig, PhD (Member)	Date

Abstract

Air traffic controllers are responsible for directing air traffic based upon decisions made from traffic activity depicted on 2Dimensional (2D) radar displays. Controllers must identify aircraft and detect potential conflicts while simultaneously developing and executing plans of action to ensure safe separation is maintained. With a nearly 100% increase in traffic expected within the next decade (FAA, 2012a), controllers' abilities to rapidly interpret spacing and maintain awareness for longer durations with increased workload will become increasingly imperative to safety.

The current display design spatially depicts an aircraft's position relative to the controller's airspace as well as speed, altitude, and direction in textual form which requires deciphering and arithmetic to determine vertical separation. Since vertical separation is as imperative to flight safety as lateral separation, affording the controller an intuitive design for determining spacing without mental model creation is critical to reducing controller workload, and increasing awareness and efficiency. To examine this potential, a stereoscopic radar workstation simulator was developed and field-tested with 35 USAF controllers. It presented a view similar to traditional radar displays, (i.e. top-down), however, it depicted altitude through the use of 3D stereoscopic disparity, permitting vertical separation to be visually represented.

To my wife and our two precious little girls. Thanks for your support, sacrifice, and patience.

Acknowledgments

I'd like to sincerely thank my advisor, Lt Col Brent Langhals for his support, direction, latitude and patience through this effort. I owe special thanks to my colleague, 1Lt Laurienne Santana for her creative input and support as well as to Dr. Michael Miller for his technical guidance and expertise. I'd also like to thank Mr. Eric Heft for his contributions in helping make the experiment technology work so well.

Additionally I'd like to thank Dr. Paul Havig for allowing me use of the Battle space Visualization lab. A special thanks to TSgt Monica Russi and Mr. Eric Gieselman for their assistance in the pilot study and experimental design efforts.

Also, to those who opened the doors to allow this research to be carried out; CMSgt David Wilson, CMSgt Joseph Kirk, Mr. Robert Brown, Mr. James Gunn, and all the pilot study and Keesler AFB experiment participant volunteers—Thank-You.

Jason G. Russi, TSgt, USAF

Table of Contents

List of Figures

Page

List of Tables

Page

Page

Effects of Stereoscopic 3D Digital Radar Displays on Air Traffic Controller Performance

1. Introduction

"Our Airmen's ability to rethink the battle while incorporating *new technologies* will improve the varied ways our Air Force accomplishes its mission."

– Gen. Welch, excerpt from "A Vision for the United States Air Force", 2012

General Issue

Air traffic control (ATC) in the US is in need of a comprehensive overhaul to maintain the present standards of safety and efficiency as the national airspace system (NAS) is pushed to capacity (Marsa, 2009). This need has resulted in the Federal Aviation Administrations' (FAA) ongoing initiative named Next Generation Air traffic Control or "NextGen". In an effort to increase the capabilities of the existing NAS and supplement the controller workforce, there will be a heavy focus on automating many control functions as new technologies mature. This change is anticipated to redefine controllers' roles from that of active controllers to passive automation monitors.

Although NextGen technologies are years from replacing human controllers, their implications highlighted the importance of understanding vigilance limits (Wickens, 1998). Projected air traffic increases combined with budget cuts hinder the ability to hire more controllers, thus lengthening controller work durations to cope with demand. These changes make human factors (HF) limitations increasingly critical to understand in the context of air traffic controllers (Erzberger, 2004). This is especially true when one considers controllers' primary function is to maintain a heightened level of vigilance and situation awareness (SA) to detect deviations and separation losses to predict and avoid potential conflicts. This workload is mentally tasking and understanding the ways to manage, measure, and mitigate the negative impact of this workload is crucial.

Current ATC in a radar environment requires constant mental calculations to infer the vertical distance between aircraft by adding and subtracting the textual display of altitude for many aircraft. Additionally, this task requires the projection of trajectory and altitude changes. Each of these are performed often dozens of times a minute. These mental manipulations allow a controller to create a "mental 3D image" of the traffic scene through mental interpretation of alphanumerical altitude data (Wong et al., 2008). This is known to be a mentally fatiguing practice and current stereoscopic display technology exists that may permit these mental calculations to be reduced. Due to the rapid pace and complex nature of ATC duty and the HF limitations regarding vigilance, SA and fatigue, it is imperative that any technology with the potential to increase human performance in these areas be explored.

These particular aspects of ATC HF have recently been highlighted with several highly publicized air traffic controller deviations. In Kentucky a severely fatigued controller, having gotten a mere 2 hours of broken sleep in the 24 hours leading up to the incident, cleared an aircraft for takeoff on the wrong runway leading to a mishap including 49 fatalities (NTSB, 2007). Additional suspicion can be raised for the human performance implications evidenced by a rash of several instances where controllers were caught falling asleep on watch among other infractions nationwide (Luna, 1997). Additional errors of perception or task saturation through workload have led to notable failures and mishaps in the system. Flight safety is critical for the future success of our air transportation system and the HF aspects of ATC must be fully understood to mitigate human error potential to the maximum extent.

Tasked with managing the safe and expeditious flow of aircraft; separating them from one another and terrain; it is incumbent upon the controllers to remain engaged and vigilant, detecting and correcting deviations and conflicts (FAA, 2010). Air traffic controllers are responsible for directing air traffic based upon decisions made using vast amounts of ever-changing information from a diverse array of peripheral (static and dynamic) displays and presentations, (FAA, 2012:2-1-1). Their task includes identifying aircraft and detecting potential conflicts among them, while simultaneously developing and executing plans of action for all aircraft within the entire airspace. With the exponential increase in air traffic expected to continue in to the foreseeable future, controllers' abilities to maintain vigilance and heightened situation awareness for longer durations with increased workload will become even more imperative to safe ATC operations within the National Airspace System (NAS).

In the FAA's NextGen scheme, Automatic Dependent Surveillance-Broadcast System (ADS-B) equipped aircraft will revolutionize how aircraft are separated (McCallie, 2011; Magazu III, 2012). This new technology incorporated under NextGen will permit aircraft to continuously broadcast aircraft location, speed, and flight information and provide this information in each aircraft to create automatically self-separating traffic (Mc Callie, 2011). Therefore controllers are expected to transition to passive roles of monitoring self-separating traffic and become responsible for monitoring larger numbers of aircraft. As a result, the workload, tasks and workstations of these controllers will change dramatically (Prevot, Hemola and Mercer, 2008). Of particular interest is the propensity for humans to become complacent in situations where active involvement and mental engagement is limited or omitted resulting in waning awareness and vigilance decrement.

As controllers assume this monitoring role, it also stands to reason that the area of responsibility for each controller will increase--as well as the volume of traffic in their given sector of responsibility--as aircraft self-separate, the equivalent perceived workload will be reduced hence the increase in aircraft to controller ratio. This may prove to be a dangerous transition from a HF standpoint unless the human performance limitations are clearly understood and addressed by providing operators with the best presentations possible to execute their duties *intuitively*. At a minimum, the displays used for this task ought to be as advanced as the system in place for self-separation and permit a controller to see a comprehensive representation, aerial "airspace activity model" commensurate to the level of complexity being experienced and shown in an easy to comprehend manner.

A particularly important display is the radar workstation, which portrays a God's eye view of the airspace, showing a 2D, top down representation of each aircraft. Supplementary information, including aircraft identification and altitude, are displayed through text labels assigned to each aircraft, often referred to as "data blocks". When using this workstation the air traffic controller monitors the location of each aircraft within the three-dimensional airspace, creates an understanding of the location of each aircraft by viewing their location against a ground plane and then reading and temporarily memorizing the altitudes of each aircraft to complete their mental representation. Below, Figure 1 is an example of a current USAF digital radar display workstation.

Figure 1: USAF Controllers at Present Day Digital Radar Workstation

In an effort to improve upon the current ATC display, a simulated stereoscopic radar workstation was developed and field-tested with 35 USAF controllers. This workstation presents a view similar to traditional radar displays but depicts altitude through the use of stereoscopic disparity, permitting vertical separation to be visually represented as differences in disparity. This top-down view is intended to reduce clutter by omitting, through toggle selection, supplementary “data blocks” (superfluous when particular aircraft are not of primary or immediate concern) that hold altitude codes, replacing them with visual disparity cues. Furthermore, the workstation is intended to reduce “scan” frequency, (when a controller visually scans their entire area of responsibility to detect and identify potential conflicts), minimizing lost time and distraction, or SA decrement, from unnecessary scans.

As the final responsibility for flight safety remains with the human controllers, their ability to observe the increased traffic volume accurately and in an intuitive manner will be increasingly critical for maximizing efficiency, maintaining awareness, and limiting fatigue. Displays are all controllers have to rely on for ensuring the safety of millions of flights a year, so their presentations should be as easily understood as possible while providing the most accurate representation of real-time traffic. See below figure for example of traffic increases as displayed on a radar scope.

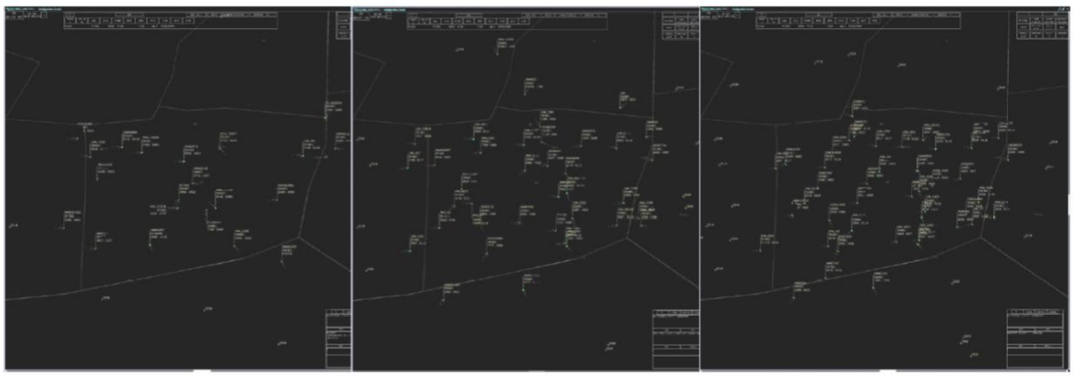


Figure 2: Current day ATC display with 1x, 2x, and 3x traffic load (Prevot, Homola & Mercer, 2008)

Research Objectives and Hypotheses

This research investigates and identifies some potential impacts of stereoscopic displays in ATC such as fatigue reduction, decision-making, perceived workload and situation awareness enhancement. The potential for a controller's vigilance to wane rapidly when not actively engaged in communications and making separation decisions is a significant concern in air transportation safety and recognized as the primary limitation to industry growth (Parasuraman, Molloy & Singh, 1993. There exists a need to evaluate the specific human factors involved to ensure human performance in this capacity before auto-separating NextGen ATC it is fully implemented (Salas & Maurino, 2010).

This paper will propose a new stereoscopic workstation; including its design, expected utility, field experiment, and an analysis of data collected from the field experiment.

The objective and goal of this research is to determine the potential positive and negative impacts of stereoscopic 3D when used in the complex application context of air traffic control. From a human factors and performance perspective, it is imperative to determine how this technology may specifically improve controller effectiveness through heightened situation awareness and reduced mental fatigue and strain. Also of concern is the potential efficiency improvement by permitting controllers to infer data more easily through a simplistic and "natural" presentation of aircraft altitudes thus allowing one to rapidly determine spatial orientation of targets in a simulated 3D dynamic model of the airspace.

This technology and the prototype created for this research has specifically been intended to be used as a "decision aid". This determination may seem like a limitation, but the controller must be afforded immediate access to rapidly changing information upon which to make vital decisions in the interest of flight safety. Therefore, any decision aid enhancing the controller's ability to gain, process and *use* the information presented in a radar environment is therefore a benefit.

Controller reliance on peripheral automation and digitized radar displays has grown and its prevalence in the workspace has rendered it indispensible for all duties related to ATC. Therefore making the best use of the technology available to ensure a controller has the most accurate, timely, and most importantly, easy to comprehend information upon which to base decisions is imperative to flight safety in every segment of controlled airspace in the NAS. From a HF perspective, the displays must not only be intuitive, they must present information and raw data the controller needs quickly, ready to employ, and be used to support controller´s decision making in a specifically pertinent manner conducive to the specialist's duties; in this case, separation of aircraft. Therefore the research question of this paper is therefore:

Does stereoscopic 3D presentation of digital radar displays enhance controller performance and effectiveness?

Methodology

As previously indicated, the methodology utilized in this study was that of an experiment carried out on actual USAF air traffic controllers. Chapter III contains extensive details of the methods and procedures utilized in accomplishing this.

Summary

This chapter introduced the reasons for and manner in which this research was approached and conducted as well as some early predictions of the impact. The next chapter, Chapter II, will detail what the predominant literature in these areas indicates. Within this review, human factors, human-machine-interaction, display technology, and performance measures along with empirical evidence from earlier works will be discussed. Hypotheses will be formed and outlined in this chapter as well. Chapter III will include an in-depth disclosure of the manner in which this research experiment was carried out to include all aspects of the experimental design, employment, focus and some preliminary findings. Next, Chapter IV will further elaborate upon the results gathered from the participants during the experiment. Using statistical analysis, those results will be discussed and compared to the hypotheses laid out in Chapter II.

II. Literature Review

Chapter Overview

In this chapter, relevant research pertaining to the enhancement, testing and creation of air traffic controller displays will be explored. It contains an extensive, however by no means exhaustive, literature review with specific focuses upon the implications of and varied applications for many types of 3D display applications for ATC. This chapter results in the generation of six specific hypotheses, a variables relationship model and measurables for each metric. There will also be a brief discussion pertaining to the overarching requirement for high situation awareness that impacts the entire discipline as well as a theory that best supports the need for this technology's development to provide this capacity.

ATC Considerations

The NAS consists of a vast network of people and equipment designed to provide a safe and efficient national aviation environment. ATC is a service provided by ground-based controllers that work within the NAS to direct aircraft on the ground and in the air. Controllers are responsible for managing and coordinating the flow of air traffic and ensuring safe flights, arrivals and departures, while maximizing efficiencies where possible and ensuring safety above all through the use of standard separation minima between aircraft as prescribed by the FAA.

ATC is a dynamic environment where controllers constantly receive a large volume of information from multiple sources to monitor the changes in the environment, make decisions, and perform effective actions in a timely manner (Xing & Manning, 2005). The role of controllers is a critical one. The ATC system's intricacies include thousands of separate facilities all communicating with each other and handling information via different sources (e.g., radar screen with a series of automated visual cues, paper or electronic flight progress strips, radio and interphone communication). Air traffic controllers have to deal with all these different sources of information to identify potential conflicts and along with strict regulatory guidance, provide timely resolution of these potential conflicts.

Background and Related Literature

An enormous amount of research has been conducted to understand the application of stereoscopic displays for command and control, air traffic, and system operators of every sort. Although stereoscopic displays have been around for over 150 years, including Wheatstone's Stereograph created in 1838 (McIntire et al, 2012), the current surge of interest is attributable in part to the vastly improved quality of the display methods currently in use. Additionally, societal impacts such as 3D use in mediums like video games, movies, home theaters and televisions, even mobile phones and tablets has led to more acceptance of the technology in mainstream culture.

Stereoscopic 3D is a method of viewing 2D images or dynamic scenes by tricking the brain into detecting depth. Human vision is already in stereo as each eye is positioned differently in the skull providing a slightly different perspective. By providing each eye with images from a slightly varied perspective, or angle of view, the images seen separately by each eye will be fused into singular images in the brain to gain a sense of depth, even when each eye is only seeing a 2D image. Active shutter stereoscopic technology allows clarity by eliminating “crosstalk”, a phenomenon that occurs when eyes see images intended for the other. Active shutter actually blocks the non-viewing eye while the other views and vice versa so images only reach the intended eye—this equates to high fidelity 3D views in most cases. Stereoscopic viewing can induce eye-strain, fatigue, and other physiological discomfort such as feelings of disorientation or nausea if improperly set-up. With responsible configuration and management of the equipment, comfortable long-term viewing can be achieved. Some other types of 3D viewing exist and have been explored for ATC and will be discussed later in this paper.

Information is abundant, however, having what you need when you need it is no longer the problem; it is the ability to access and process it for use quickly that has become the limiting factor. This requirement falls squarely on the information technology and human-computer-interaction fields as the need for better organization of displayed information along with intuitive displays is demanded. With the sheer amount of available information we attempt to present in any given new display, the manner in which it is presented may be instrumental in its usability, making stereoscopic views a potential enhancement for complex information systems.

Human Factors and ATC Performance

Air traffic controllers need to be provided with the necessary information to make timely and effective decisions. In addition to designing systems that provide the operator with the necessary information, it must be provided in a cognitively usable way (Endsley & Garland, 2000). If information provided by the tools overwhelms controllers' cognitive capacities, critical information could be either missed or misinterpreted and put performance at risk (Xing &Manning, 2005). For air traffic control, complexity reflects the difficulty involved in formulating an accurate representation of the situation, given many sources of information about aircraft, sectors, and flight rules (Xing & Manning, 2005). This is best described as the mental modeling that a controller must perform to comprehend the aircraft positions in spatial orientation to one another.

The 2D display does not show altitude in an intuitive way, this interpretation becomes one of the most mentally tasking aspects of the performance of controllers' duties. The conversion of altitude to for a 3D representation is an important concept that needs to be considered when designing a system in an ATC environment and it must be accomplished to develop full situation awareness (SA). In a study questioning student controllers about this mental task one stated, "*It's like a box, I guess, but it is hard to explain, but it is 3D in your head. In my head it has to be 3D and so …if this is the [aircraft] itself, I imagine it being in a 3D box*", (Tavanti and Cooper, 2009). Refer to the Figure below that represents an image of what a controller attempts to create as a mental model of activity and relative vertical spatial orientation from the 2D display.

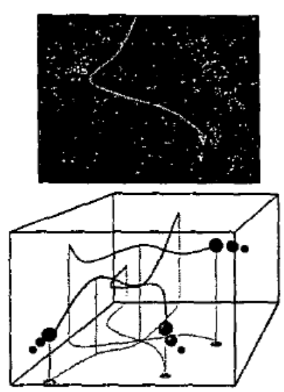


Figure 3: Representation of Controller's Mental Modeling of Flight paths (Dang-Nguyen, 2003)

A simple model of an operator's cognitive task of filtering through vast arrays of information and detecting what is needed in order to inform decision making is illustrated in Figure 4 (Endlsey, 2000). Ensley indicates that the amount of data is immense, however depiction of the data in a form such that it is available to the human needing it can cause a critical break-down in the information transfer which she refers to is as the "Information Gap". This fundamental concept is often overlooked in the design of human-machine interfaces. According to Endlsley (1995), in many systems, operators and decision makers are bombarded with far too much information to sort, leaving them less informed as they are unable to quickly access the information they really need from the immense stream of data in a timely manner. The researcher posits that a more intuitive interface, that presents the data intuitively will provide heightened situation awareness (SA), permitting the operator to gain and process the needed information more rapidly.

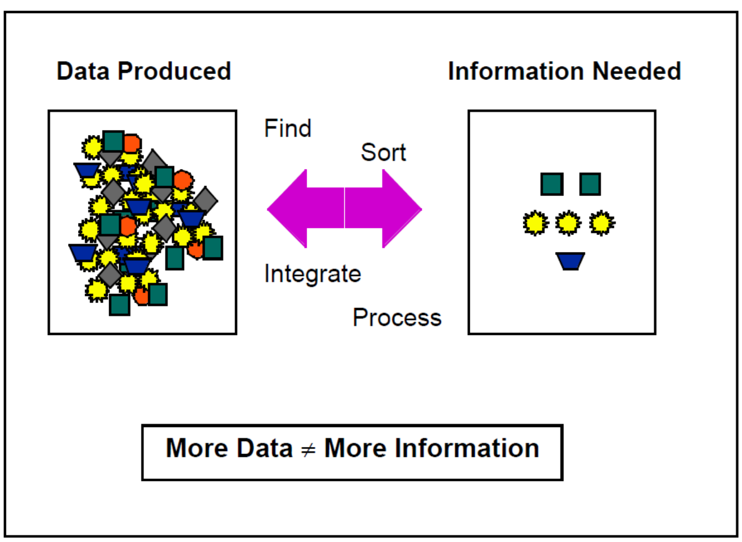


Figure 4: Endsley's Information Gap

2.5-D, Slant-View 3D in 2D, and Virtual Reality

There has been extensive investigation into the applicability of 3D viewing for the purpose of air traffic control. As early as 1948, papers were written examining the potential for 3D displays of radar images (Parker and Wallis, 1948; McIntire, Havig, and Gieselman, 2012). Numerous forms of radar image generation have been investigated for ATC applications; including side-view, slant view and pilot perspective. Below is an example display from a recent experiment with slant-view 2D with 3D depth cues.

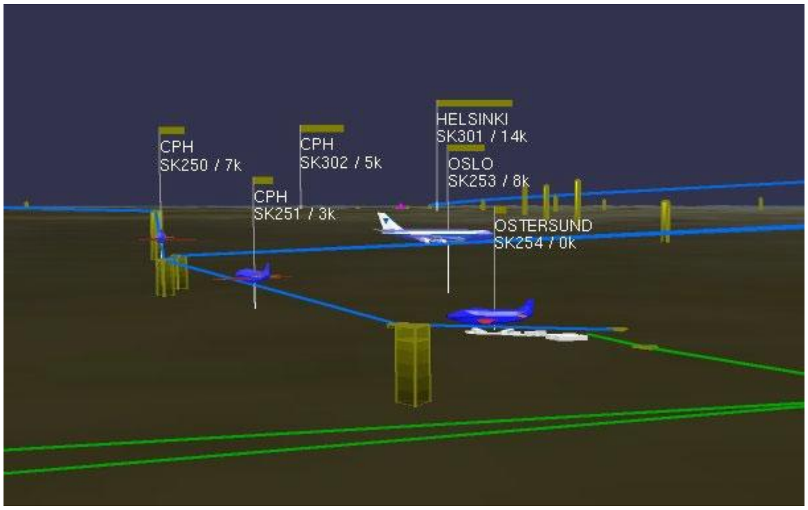


Figure 5: 3D in 2D Display, Lateral Separation to Horizon Obscured (Bourgois et al, 2005)

An inherent limitation to this presentation is that lateral separation loses scale as aircraft depicted are further away, (nearer the horizon line), just as in real life the targets become smaller and more difficult to discern reducing its usefulness for determining separation. This limitation is recognized by Tavanti et al, who stated, “visualization systems where the users are expected to discover relations based on Euclidean distances or shapes will be ineffective” (Tavanti, Le, and Dang, 2003).

Additionally, the side-view or slant-range perspective induces far more on-screen clutter in the form of topography, mapping and 3D depth cues along with overlapping data tags and drop lines as aircraft pass that are more than sufficiently separated laterally increasing the difficulty of determining critical conflicts as this is 3D in 2D using only depth cues for reference., not visual disparity.

Research has demonstrated that stereoscopic display technologies are considered, “indispensible” for viewing complex and extensive high-dimensional scientific data and objects especially in a dynamic and temporal (4-D) capacity (Chau, McGinnis Talandis, Leigh, Peterka Knoll, Sumer, Papka, and Jellinek, 2012).). However the applicability of stereoscopic viewing for the purpose of air traffic control potential has been met with mixed results (Parker & Wallis, 1948; McIntire et al, 2012). In an ATC context side-view combined with a top-view, commonly referred to as “coplanar”, slant view and pilot perspective stereoscopic methods have been evaluated. An inherent limitation to slant view or pilot perspective stereoscopic methods is that lateral separation loses scale as aircraft are depicted farther away just as in real life the targets become smaller and more difficult to discern at a distance. This limitation renders these views useless for the purpose of determining whether separation minima exist between aircraft. According to Tavanti et al, there is a consistent deficiency in this type of display with regards to the unknown distance along the depth axis, affording little to no reference to the horizon line (2003).

Virtual reality (VR) caves and other types of semi-immersive control interfaces have also been investigated and were found to have limitations when applied to facilitate air traffic control functions (Persiani and Liverani, 2000). Besides being physically cumbersome to view by requiring complete body repositioning to view 360 degree environments, they lack ground and focal reference which can be disorienting to the user. These immersive displays lack the ability to provide a large scale depiction containing an operator's entire area of responsibility within a single field of view (FOV) simultaneously. Similar to the slant and side views, they offer little to no reference for depth and limit the viewer's line of sight to one direction at a time severely hindering one's ability to maintain vigilance and obtain situation awareness over their entire area of jurisdiction. VR caves have potential for training and orientation, such as learning the limits of a new facility's airspace or other physically prohibitive experiences; however their current limitations make them an ineffective alternative to current day top-down radar viewing methods.

If stereoscopic viewing is to be useful for air traffic control operations, it must simultaneously depict lateral and vertical separation. Recent advances in technology allow for improved "top-down" viewing of a 3D world. As a result, this study focuses on the effects of providing a top-down stereoscopic 3D view for air traffic control operations. Such a system maintains the perspective available to controller's in today's system to allow the controller to rapidly grasp the lateral separation, while using stereoscopic disparity to depict altitude, permitting the controller to assess the vertical separation based on perception of depth afforded by the stereoscopic top-down view. The following sections highlight the expected effects of incorporating stereoscopic 3D into traditional ATC displays through a top-down view.

Situation awareness (SA) and Dynamic Decision-Making

Situational awareness is the focus of a controller's training and the development of this skill as well as the ability to maintain it is critical. It is defined by Endsley as, "The perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." (2000). Refer to the model by Endsley in figure 6 below depicting the variables interacting through the multiple levels of situation awareness.

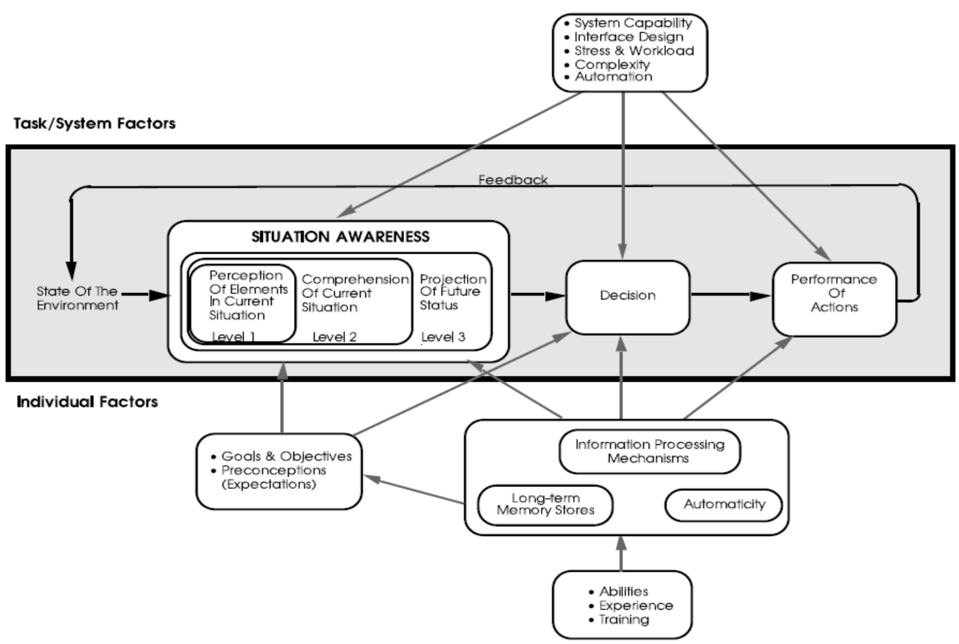


Figure 6: Endsley's Model of SA in Dynamic Decision Making (2000)

Decision making, in the context of air traffic control systems, is a continuing activity that utilizes the controller´s comprehensive understanding of information at several levels of detail, together with the controller´s knowledge of rules, procedures and instructions and their permissible flexibility (Hopkin, 1995). The cognitive tasks of ATC are what make the profession a demanding one. The continual use of memory, redundant call-up and execution of many tasks pertaining to a vast array of differing situations warrant an enormous capacity for situation awareness, decisive confidence, and keen observation skills.

The critical determinant of a controller's performance is their ability to detect the need to make corrective separation maneuvers, primarily by inferring information on aircraft positions from a display. Signal Detection Theory examines how much more tasking it is for one to detect small differences in large arrays or presentations of seemingly similar data during visual search (1966). This is especially applicable to a controller as the variances that are being tracked, and therefore, manipulated by the controllers are often very slight and presented poorly in textual form with conventional 2D displays. The cognitive task associated with continual scanning to detect changes in the form of slight nuances relates strongly to the time to detect and performance of missed opportunities for detection. Detection tasks demand a heightened and strong sense of situation awareness.

This researcher asserts that any tool, decision support system, (DSS) or otherwise, that reduces a controller's mental workload and potentially increases their SA is a good one. Controllers are decision makers in a dynamic environment. Their success requires constant updating, mental processing and application of relevant information in the interest of conflict detection and avoidance through the issuance of specific detailed instructions to every pilot operating in their area of jurisdiction.

It has been found that a controller has far better recall about aircraft upon which they provided more control instructions than aircraft that were merely transitioning their airspace or that they were only monitoring (Means et al, 1988). This is of particular interest when one considers the future of ATC and the self-separating systems that will move controllers into a passive role as monitors; this being a similar capacity to the manner in which subjects' skills were employed in this study. There exists little research on how controller conflict detection will be impacted by the passive monitor role (Metzger, Dornier, Wessling, Germany, and Parasuraman, 2001). The cognitive effort exerted by the controller in understanding certain characteristics about an aircraft also seems to relate to their retention of information. In a study conducted by Gronlund, Bain and Manning in 1997, it was found that controllers considered altitude (83%) and position (67%) to be the most important factors to remember. They also found that this was chosen over other vital flight information such as route, destination, type aircraft, call sign, speed and time over fix. This reinforces the clear importance placed on altitude and spatial orientation relative to one's airspace by a controller. This result is not surprising when one considers their primary function is ensuring safe separation above all else.

The following, Figure 7, is an example using simple 3D (2.5D) graphics of the spatial orientation of two aircraft in a cylindrical section of airspace with boundaries depicted as transparent. This is the type of mental modeling from a 2D display top-down presentation using textual altitude codes. The mental image creation is tasking for a controller and this example illustrates how it is employed, although cues such as drop lines, space boundary and vertical scale are not imagined—they are comprehended. As this scene changes, based upon instructions given and executed, the controller must constantly update their 3D mental model to permit a clear understanding of all the aircraft under his/her authority and maintain that separation.

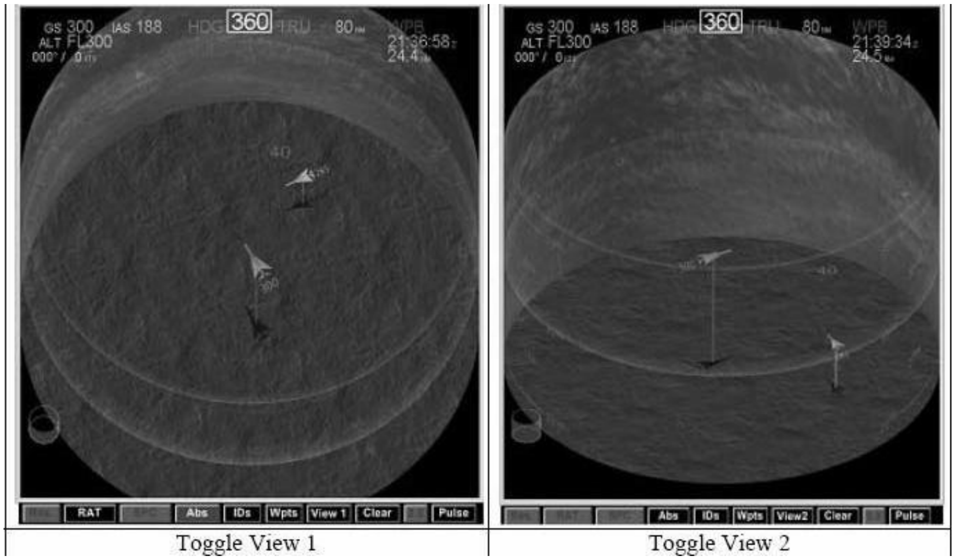


Figure 7: Coplanar 3D in 2D view of 2 aircraft with depth cues (Thomas and Wickens, 2006)

Figure 8 shows a simplified side view of several aircraft flight paths at varied altitudes and varied changes in altitude and their impacts on conflicts based on timing. This concept has been experimented with EUROCONTROL using what is called coplanar workstations that offer a top-down traditional view as well as a type of "side-view" to determine vertical spacing. However, the drawback of dividing one's attention between two large displays as well as attending to duplicates of aircraft tracks is the potential for error as operators must attend to their primary presentation at all times, making the introduction of peripheral displays a potential distraction.

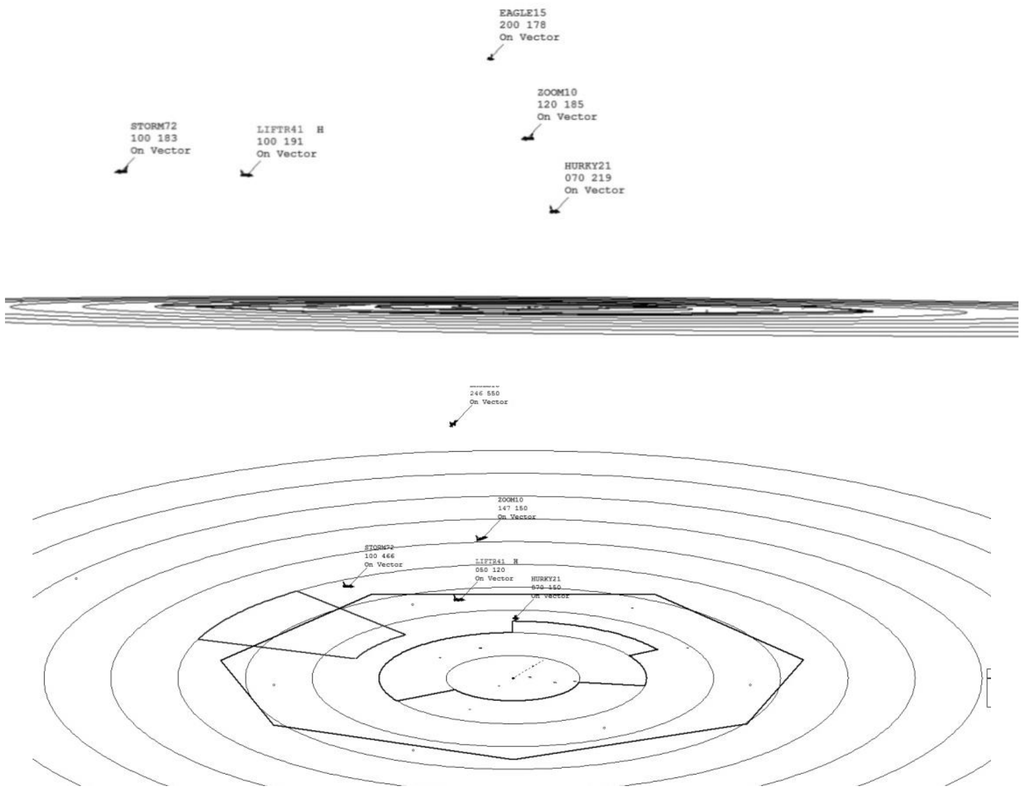


Figure 8: Slant-range and Side-View Examples from SIGNAL software

Creating a stereoscopic 3D view of traditional top-down digital radar displays affords the controller the best possible perspective, preserving both the scale and lateral separation while providing a scale-accurate depth perspective to assess vertical separation. By providing simultaneous vertical and lateral separation, it is hypothesized that situational awareness will be enhanced resulting in the following first hypothesis:

H1: The use of stereoscopic 3D digital radar displays will have a positive effect on controller situation awareness and conflict detection.

Mental Modeling, Memory and Recall

The role of recall and memory in ATC is imperative for certain duties. Recalling rules and regulations, potential outcomes of a given scenario from experience, or knowing how an input will interact with a dynamic traffic flow are all critical abilities for air traffic controllers. However, actual memory of a specific situation has positives as well as drawbacks.

Hopkin suggested that a controller's ability to forget the last altitude or vector given to an aircraft can permit them to replace that data with the current or next assigned characteristics (1980). This memory management may prevent older information from interfering with the newest information, permitting a controller to maintain better awareness of their traffic (Gronlund et al, 1997). Further research has evidenced that the mental refresh rate can contribute more to the misperception of the true model as what an operator understands to be happening becomes out-dated information. Fundamentally, the ability to present information and then permit its easy replacement with updated data may be more desirable in ATC (NATO, 1982:36).

In a 2004 paper presented to the International Journal of Aviation Psychology, a controller's cognitive task was defined as;

> Given the dynamic nature of ATC, the temporal aspects of controllers' mental picture are apparent, as are the temporal demands of their tasks: Controllers need to anticipate aircraft trajectories and pilot intentions well into the future, plan their actions, and then execute the planned actions at a proper time and in an appropriate sequence. (Rantanen, McCarley and Xu, 2004)

This is commonly referred to as "The Picture" by air traffic controllers. In fact, when one controller relieves another, it is the responsibility of the one being relieved to ensure the on-coming controller has a satisfactory concept, or "Picture" of the traffic before departing the workstation (FAA, 2012). Steven Shorrock has written much on air traffic controllers' mental picture and its importance, (eg. Mental Imagery in Air Traffic Control, 2010; Errors of Perception in Air Traffic Control, 2007). He states that there is an absence of emphasis on this important ATC concept and the implications of learning imagery, perceiving it and adapting it into technology design are significant. He also indicates that mental imagery is a, "controversial subject in psychology" albeit an imperative one to understand in the matters of ATC performance measures (2010).

As with any mental formulation or processing of information, whether it is memory of pictures, scenes, activities, faces or text, the accuracy lies in one's ability to perceive the information as intended. The ability of the controller to take 2D presentations of aircraft in flight and mentally formulate a complex, dynamic mental model is, "a vital cognitive component of their job" (Shorrock and Isaac, 2010). This leads one to believe that any mistakes in perception can lead to mistakes when decisions about aircraft separation are made based upon these mental models. Jones and Endsley found that 76% of pilot errors were a direct result of misinterpreting presented and available information (1996).

This makes the heightened awareness of activity pivotal to ensuring the mental image accuracy in dynamic environments such as ATC (Endsley, 2000). Endsley goes on to infer that mental models are imperative tools for SA building and maintenance. She indicates that they are a method for unifying data into usable projections to anticipate future events (Endsley, 2012) and that "Errant Mental Models" can result from missing an integral, although minute, detail that has changed therefore altering one's entire concept. This could be a course variation, or slight delay in a climb or descent.

Given the importance of the mental model to air traffic controller performance and the effect of recall accuracy on establishing a reliable mental model, hypothesis 2 is as follows:

H2: The use of stereoscopic 3D digital radar displays will have a positive effect on controller recall accuracy of aircraft vertical position.

Perceptions of Fatigue

Of human factors studies in the aviation industry, few are more thoroughly examined or regarded as important as that of fatigue management. There is a preponderance of literature examining aircrew and controller fatigue issues to include circadian rhythm, work and rest cycles, and crew rest period interruptions among others. Fatigue can be defined as, "…a decrease in performance capability as a function of time on task" (Salas and Maurino, 2010). Unfortunately, in this researcher's observation, this is due largely to the fact that fatigue is the most frequently cited reason for major aviation mishaps.

There are many aspects of ATC training and procedures designed for the purpose of fatigue management and almost all involve dedicated rest periods, crew resource and workload management of some sort. However, the predominant existing research concerning fatigue focuses upon the physical wakefulness and time at and away from the duty location and workstation; not the impact of the technologies employed to assist the controller in the performance of their duties.

In this study, the fatigue focus is on that which is induced through cognitive tasks and workload associated with the use of the presentations from which controllers derive their mental models. Controllers have an unusually high intensity of demands on their senses having to process vast amounts of data often for durations of two hours or more at a time (Shorrock, 2006).

Certainly the fatigue issues of controllers are not the same as long-haul pilots who fly 12 hour trans-meridian flights; however, there are basic task-specific considerations. Of primary concern is that of the controller's ability to maintain vigilance when the workload is low. It has been published that there is a consistent reduction in controllers' signal detection efficiency following a significant workload, (surge of traffic), resulting in most operational mistakes taking place under light to moderate workloads (Redding, 1992). Perhaps improved human-computer interfaces and intuitive presentation of information can reduce this trend.

Given the cognitive nature of the tasks, it stands to presume a more intuitive display that allows a controller a more realistic depiction of the activities in their airspace will minimize their mental task-load and therefore slow the onset of fatigue resulting in the following hypothesis:

H3: The use of stereoscopic 3D digital radar displays will decrease controller fatigue.

Perceptions of Workload and Task Difficulty

It has been extensively studied and agreed upon by many in the human performance field, that temporal and mental demands comprise the largest portion of a controller's workload in ATC (Rantanen, McCarley, and Xu, 2004). The limiting factor to the growth of the air traffic volume is also known to be the air traffic controllers' limitations on monitoring and controlling separation of traffic within each, increasingly saturated, airspace sector. It has been determined as recently as 2004 that the maximum safe operating number of active aircraft per operator is 15 at a time (Erzberger, 2004). In the author's experience, this is a significantly high workload by any controller's standards and perhaps unrealistically high to maintain for any substantial duration.

As cited earlier in this report, the primary contributor to workload in the controller's task is the 3D mental model creation from the 2D presented information. In addition to this workload is the labor intensive manner in which current operations are conducted, namely in controller-to-pilot communications for verification purposes. An example of this is the needed number of radio transmissions to ensure the pilot and controller understand each other and instructions are received and adhered to. In a study of communication delays, it was explained that when a controller is attempting to verify an altitude due to a data tag's temporary absence or a rapidly changing situation, he or she will have to query a pilot and await the response. The pilot will respond, generating another question or instruction issued by the controller and then, again, waits for a pilot response (Rantanen, McCarley, and Xu, 2004). This is an inefficient method and could seemingly reduce the questions a controller may have about aircraft activities as it will be displayed very apparently in the 3D model provided by the display. This leads the investigator to the following additional two hypotheses:

H4: The use of stereoscopic 3D digital radar displays will decrease controller perceived workload.

H5: The use of stereoscopic 3D digital radar displays will decrease controller perception of task difficulty.

Perceived Display Induced Distraction

Tavanti and Cooper discovered that the 3D technology itself presents the needed information in such an intuitive manner that it poses little distraction for the users (2009). This finding coincides with additional research done in the field of auto stereo 3D desktop applications for scientists where the ability to focus on the science problem presented without distraction has been the focus, presenting that field with seamless and non-intrusive new display technology (Chau et al, 2012). In Chau's study, the investigators determined that stereoscopic presentations of data permitted the user to focus their attention quickly on the specific information they sought more readily even on large congested and "cluttered" displays.

This relates very well to ATC where it has been found that much of a controller's time is spent making superfluous "scans" of the screen and observing and "re-visiting" aircraft tracks that are of no immediate concern. Perhaps by presenting the tracks with depth, their vertical separation will be obvious enough that a controller will be able to "filter" through the traffic that is operating in safe proximity and quickly zero-in on those with less time to loss of separation (LOS) enhancing detection while minimizing distraction.

Another important performance aspect is that of short-term and "prospective" memory (Wickens, 2002). This type of memory is specific to remembering that something needs to be done in the near future and is considered a very poor human characteristic in multi-tasking contexts (Wickens, 2002). This can be attributed to the high potential for distractions that may divert attention. This can be best illustrated by a controller assigning an altitude to a departing aircraft much lower than the aircraft's requested level due to other traffic precluding the immediate climb. A controller will often utilize a tactic such as "cocking the strip" where they will literally position a paper flight strip associated with that flight in a particular manner as to assist them in recalling what to do when they're able—sort of a string-on-the-finger memory jogger. Unfortunately, these tactics are workload permitting and are inconsistently utilized resulting in inefficiencies such as a pilot being held low for longer than required because a controller forgot to eliminate the restriction and permit the climb. If one were to imagine this sort of mistake on a magnitude of thousands of times a day, even when a climb to a more efficient fuel-burn altitude is delayed even for a minute or two, perhaps millions of dollars in fuel expense could be realized. This leads to the final hypothesis:

H6: The use of stereoscopic 3D digital radar displays will decrease controller distraction.

Supporting Theory

Channel Expansion Theory

A highly regarded and very useful theory in the discipline of human-computer interaction and information technology is that of Channel Expansion by Carlson in 1995. This particular theory concentrates on the importance of a channel or media's richness, or its ability to convey meaningful and clear information as an information technology. This is certainly applicable when investigating the impacts of new IT for use in a time-critical decision-making environment such as ATC. Carlson and Zmud indicate how individuals develop perceptions of a medium's ability to provide rich communications as dynamic, changing and developing over time with exposure to the computer-mediated-communication, (CMC). Their findings reveal that people's perceptions vary over time with their usage and with exposure and users may hold varied levels of confidence in a channel's ability to function specific to the applications they desire (Carlson and Zmud, 1999). This theory is simple in the fact that it refers to experiential impacts on perception, however, humans naturally have stereoscopic sight with overlapping visual fields that afford the depth disparity people are intuitively able to decipher. This makes the inherent "richness" of information displayed stereoscopically, as a CMC information technology, one of immediate interest as individuals who see it are able to quickly understand what is being shown as it provides a realistic feeling of depth and space.

Summary

There is a vast amount of literature concerning the implications of 3D displays in ATC—its advantages and drawbacks in many "unrealistic" and varied manners. However, there is little empirical evidence found in the literature on the specific human performance factors and common measurements of a controller's performance with regard to the passive monitoring role in a current-day, realistic, real-time, dynamic traffic environment or even within the confines of current standards of operation. This study will attempt to begin filling this gap in the prevailing literature on 3D use for ATC with empirical evidence gathered from the observation and responses of 35 USAF controllers.

Table 1 below outlines the hypotheses generated in this section derived from the literature review and the researcher's experience in the field.

Table 1: Hypotheses

H1: The use of stereoscopic 3D digital radar displays will have a positive effect on controller situation awareness and conflict detection.
H2: The use of stereoscopic 3D digital radar displays will have a positive effect on controller recall accuracy of aircraft vertical position.
H3: The use of stereoscopic 3D digital radar displays will decrease controller fatigue.
H4: The use of stereoscopic 3D digital radar displays will decrease controller perceived workload
H5: The use of stereoscopic 3D digital radar displays will decrease controller perception of task difficulty.
H6: The use of stereoscopic 3D digital radar displays will decrease controller distraction.

III. Methodology

Overview

The preceding chapters identified the potential of stereoscopic display technology benefits in the complex, multi-tasking, high-speed decision critical environment of ATC. This chapter will present the methodology used to investigate the research hypotheses proposed in Chapter II. Included are descriptions of the research design, pilot study, population of study, survey instrument, data collection, and the actual experiment setup and execution.

Relevant Population

This research remains applicable to the entire air traffic control population. However, for the purposes of this study, the sample population was provided by the ATC technical training school at Keesler Air Force Base, MS, as it had been previously determined the best location to conduct the experiment with the leadership's support. It was carried out using 35 USAF ATC instructors and students including both civilian and active duty. Participation was voluntary and the study lasted one week. All the participants were familiar with the air traffic procedures used in the experiment as they were derived from current standard practices and were in line with FAA and AFI guidance. To avoid compromising the study, participants were asked not to share the details of the study or talk about the questionnaires with others until the end of the data collection period.

Experiment Design Considerations

The experiment was designed to capture perceptions of the technology by the users as well as test for efficiency improvements during the experiment. All the participants were administered a brief training scenario, a control condition of 2D and an experimental stereoscopic 3D condition.

All scenarios had to be recorded prior to their exposure to the participants thereby limiting the subjects' interaction—this is identified as a limitation of the design. Based on the timeline and budgetary constraints, this was a necessary adaptation. This was also found to be quite acceptable as the scenarios remained the same for each subject since controllers were unable to modify them with their own inputs. A real-time interactive scenario, such as the standard trainer simulations controller's use that require the controller to issue instructions which are then input by a pseudo-pilot, would have been far more complex to quantify and code results as each operator would perform the tasks of separation, (through heading and altitude issuance), very differently, employing personally preferred techniques. However, by maintaining the exact same scenario across all participants by way of prohibiting instructions that would alter the traffic flow, the specifically scripted conflicts were presented in the exact same manner to all participants allowing consistent data collection through the dynamic feedback measure of conflict detection.

This experiment was designed to evaluate the controller recognition of vertical separation conflicts in a 3D environment over that of a standard 2D presentation. The experiment was run first through a brief pilot study with six volunteer participants to ensure validity. It was also evaluated by experienced air traffic control volunteers to evaluate realism, quality and concurrency with the apprentice subjects' level of proficiency and ability.

Equipment

For stereoscopic display and simulated scenario creation and modification, numerous pieces of varied equipment was procured and manipulated to achieve the desired presentation for testing. Of note, all components of this experiment were conducted with commercial-off-the-shelf technology with the exception of the SIGNAL FAA simulation software, which is copyright and government protected. Included in this final suite was the array of software and hardware listed here:

1. Lenovo Thinkpad T420i , 64 bit, intel core i3-2310M processor, Windows 7 Enterprise OS, 4.00GB memory, 300 GB HD. Used for scenario generation using SIGNAL FAA provided simulation software. This device acted as a slave to the NVIDIA equipped Dell that captured video as it was generated
2. SIGNAL Air Traffic Control Simulation Program software. Authorized use by FAA to develop and record air traffic scenarios
3. HP computer with Clickcounter freeware that was used remotely for mouse click count (conflict detection)
4. Microsoft wireless mobile mouse 3500 (2). Used by the participants for subjects' real time inputs and used by the researcher to load the scenes on the monitor
5. Epiphan DVI2USB Duo External DVI Capture box device. Used to record the simulated ATC scenarios from the originating machine (Lenovo laptop) to the receiver and recorder machine (Dell laptop)
6. Dell precision M4600 workstation, Windows Professional 7, 64 bit, 250 GiG HD, 16 GB DDR3 SDRAM, NVIDIA 3D suite, NVIDIA Quadro 1000M discrete graphics card, intel core i7 extreme processor. It was used to capture the ATC scenes and later connected to the main display that was viewed by the participants
7. StarTech display port to DVI Dual link Active Converter cable-USB powered. It was used to connect the Dell computer to the ASUS monitor to facilitate operating NVIDIA 3D active shutter display.
8. ASUS VG236 23.5" 3D 120Hz LCD display monitor (commercial).

9. NVIDIA 3D software used to load the ATC scenes that were showed for the participants
10. 3D vision USB Controller/IR Emitter. It is a needed component to NVIDIA software

All the scenarios were developed using the Signal software. They were recorded from the Lenovo computer using the capture box (commonly referred to as a “frame grabber”) to the Dell computer, which was connected to the ASUS 3D Monitor. The scenarios were shown to the participants on the 23.5” ASUS 3D monitor using the NVIDIA 3D viewer in stereoscopic with active shutter LCD glasses to provide each eye its specific view of the images.

For the experiment, three scenarios were recorded: training, control, and experimental. The training scenario was developed to allow the controllers to get familiarized with the experimental process and with what the study focused on prior to collecting measurements. However, they were not presented with the new technology until the experimental scenario. The control scenario was the baseline to compare controllers’ performance, although it was not necessarily their first exposure. The experimental scenario was displayed in full stereoscopic 3D with the peripheral headgear of wireless IR active shutter 3D glasses. This was the participants’ first exposure to the 3D presentation and a 20-second delay was built into each scenario to allow their eyes to adapt to the stereoscopic view before measurable activities commenced. Verification of this adaptation was done by verbal questioning to verify they indeed were seeing a disparity view.

Questionnaire Development

Please refer to Appendices F, G, and H for actual copies of the questionnaires utilized in this study to include demographic pre-screening and post- control and experimental treatment instruments. These were varied in their formats to permit the collection of a diverse amount of data from responses. The Pre-Screening Questionnaire and training questionnaires offered fill-in the blank, YES and NO, and Likert scales of 1 – 5 for a number of responses with 1 equating to “strongly disagree” and 5 “strongly agree”.

The Post-Treatment, (control and experimental) Questionnaires contained a screen capture of the radar scope from a time two minutes prior to the end of the scenario that prompted the participants to fill-in the altitudes from memory, using spatial reference as an aid to recall, see Figure 9 below for an example of these captures.

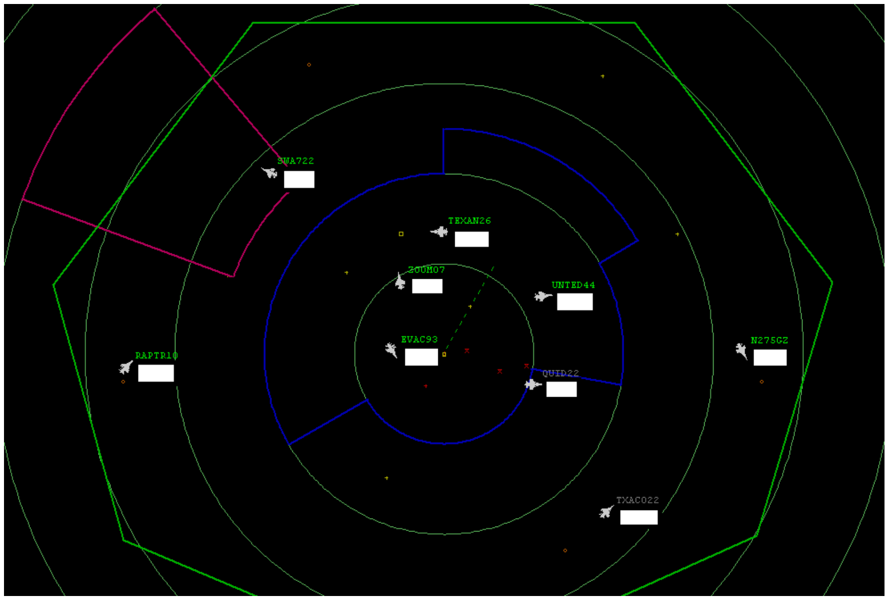


Figure 9: Screen Caption from Post-Treatment Questionnaire

The limited data bocks with the call signs remained in the screen capture as it is known controllers do not remember call signs well (Gronlund et al., 1997). It also had a number of fill-in the blank questions regarding extremes observed in the scene such as highest aircraft, what conflicts were evident and approximations of vertical separation. Likert scales of 1 – 7 were also used with 1 equating to a “No” and 7 a “Yes” with 4 coded as “Somewhat”. Additionally, there were two questions asked about the feasibility of the technology and their perceptions of it. This provided candid and frank feedback from the individuals on their observations regarded as valuable insight by this investigator.

Currently, there is no general agreement upon a correct methodology to measure SA (Gronlund et al, 1997), however the query technique is the most commonly used method as it permits one to recall what they are able to from the point in time they actually possessed situation awareness (Adams, Tenney, and Pew, 1995). This is a flawed manner in which to measure SA, however as an accepted limitation, remains the most viable method for this type of measurement that precludes the actual determination of one's actual level of awareness whilst they perform the task functions in real-time.

Pilot Study

A pilot study was carried out approximately three weeks before the initial experiment. The pilot study was conducted with six volunteers, from which two were Air Force Institute of Technology graduate students, three were air traffic controllers from Wright Patterson AFB Tower and one was a human factors researcher and ex-airline pilot. To test both the experiment design for flow and timing as well as mobility, it was conducted in the researcher's lab on The Air Force Institute of Technology campus and was packed and transported to the Air Force Research Laboratory also located on Wright-Patterson AFB, Dayton, OH.

Goals of the pilot study were to ensure that the format and techniques established in the experiment design would permit the collection of the information sought. It was also used to ensure that the timeline and script order were accurate for actual real-time administration of the study. Additionally, It was also used to determine that an intended participant would be capable of understanding what was being presented well enough to provide useful post-treatment feedback and that the difficulty posed a challenge, yet remained realistic. This created confidence in the design's ability to ascertain performance measures.

Useful feedback and observations were received from the pilot study participants. Some identified the intensity of the disparity to cause near-immediate eye strain; this was later determined to be caused by the z-scale adaptation being too drastic. Adjustment of this parameter from 30% disparity on the z-axis scale to 20%, resulted in a marked improvement in reported viewer eye comfort.

Also, due to the lack of training on the new technology and little preparation for what the technology would look like or what sort of questions they may be asked at the conclusion, study participants were completely unprepared to answer post-treatment questionnaires as they were written. The format of a fill-in-the-blanks chart indicating a side view from the surface up to the highest displayed aircraft proved to be too difficult for the participants to recall. This instrument method was abandoned in favor of a modified screen capture allowing the controllers to rely on the relative horizontal position of a target, (as described briefly in the previous section, "Questionnaire Development"), to recall its approximate vertical orientation on the scope.

Due to the difficulties participants encountered with the pilot study's format, no usable data was collected which was warranted acceptable since the purpose was to indeed detect these deficiencies and correct them. Several changes were made between subjects of the pilot study so that the last volunteer, the sixth to run it, was exposed to the actual experiment as it was fielded. Among other modifications to the experiment through the pilot study, a very brief training segment was devised and inserted as the first exposure for every participant in each segment of the experiment to better prepare them for the experiment's procedures and purpose.

Cooperation and Permission by the USAF ATC Field

This experiment involved the performance of Air Force personnel, both civilian and active duty, and was conducted in accordance with human experimentation requirements (AFI 40-402). Exemption to full Institution Review Board was sought in order to use Department of Defense personnel as volunteers for research on 3D stereoscopic radar displays and the potential improvement in controller performance with them. This exemption was granted by the Air Force Institute of Technology on 25 January, 2012 by the AFIT IRB. Additional authorization to access active duty US Air Force and DoD Civilian controllers at the technical school was granted by USAF ATC Career Field Manager, AF Pentagon Washington D.C. and the school's commander at Keesler AFB, MS on 7 January, 2012. Please refer to Appendices A and B for these authorization letters.

The Experiment

For this study the sample population was provided by the ATC technical training school at Keesler Air Force Base, MS. The study involved 35 USAF ATC instructors and students. Participation was voluntary and the study lasted one week. A primary advantage of this population was that all participants were familiar with standard air traffic procedures and displays. Experience levels varied from 2 months, to 30 years. The average years of ATC experience was 7.29 years. The average age of participants was 29.1 years and 26 of the 35 participants were male.

The subjects were volunteers and were available for up to two hours of time. Participants were briefed before starting the experiment about each section of the simulation and a pre-questionnaire was administered to gather pertinent participant demographics They were asked to monitor two, multiple-aircraft radar scenarios in both 2D traditional and a 3D stereoscopic display configuration. All the scenarios were viewed in a darkened room to best reduce the illumination loss from the active shutter glasses as well as simulate a realistic radar approach control room setting. The scenarios were designed to be as realistic as possible in order to test the hypotheses of interest. The scenarios included a mean of eight aircraft, two departures; two aircraft had no supplementary data tags--an entirely realistic scenario in actual ATC operations.

The SIGNAL software provided familiar training simulations using a simulated terminal environment created specifically for use by the USAF ATC technical school where the experiment was conducted. This simulated airport is called, “Canyon” and was very familiar to all participants and chosen specifically for this reason. The mapping and type of aircraft and the characteristics of these, as well as their typical call signs, were used for familiarity by the subjects. This pseudo airport was used to generate the entire set of scenario recordings used which was recorded ahead of time to permit both stereoscopic conversion and maintain control over the presentations for uniformity.

The experimental 3D scenarios were presented on the ASUS 23.5” monitor, (see, “Equipment”) with the targets shown as “protruding” to draw attention to and exaggerating their vertical separation in addition to their lateral spacing. This was done using stereoscopic viewing through left eye/right eye disparity and channeled using the NVIDIA 3D vision active shutter viewing glasses and IR emitter. The control scenarios were also presented on the same display without the peripheral NVIDIA 3D equipment activated.

The workstation developed and used for used for the experiment can be seen in Figure 10. The researcher expected the subjects' performance to increase for detecting true vertical separation conflicts and altitude deviations when observing traffic in a 3D presentation. It was anticipated that the reduction in supplementary information or the need to read and calculate constant altitude readouts to produce a 3D mental image will reduce mental fatigue thus allowing controllers to maintain SA for longer durations before tiring, this being suggested and supported by the literature. It was also anticipated that a certain number of subjects would respond poorly to the 3D images as this type of viewing can induce headaches, dizziness or disorientation in certain individuals who have poor stereopsis. To mitigate this danger, a brief questionnaire and two-minute exposure was conducted prior to the experiment for each subject.

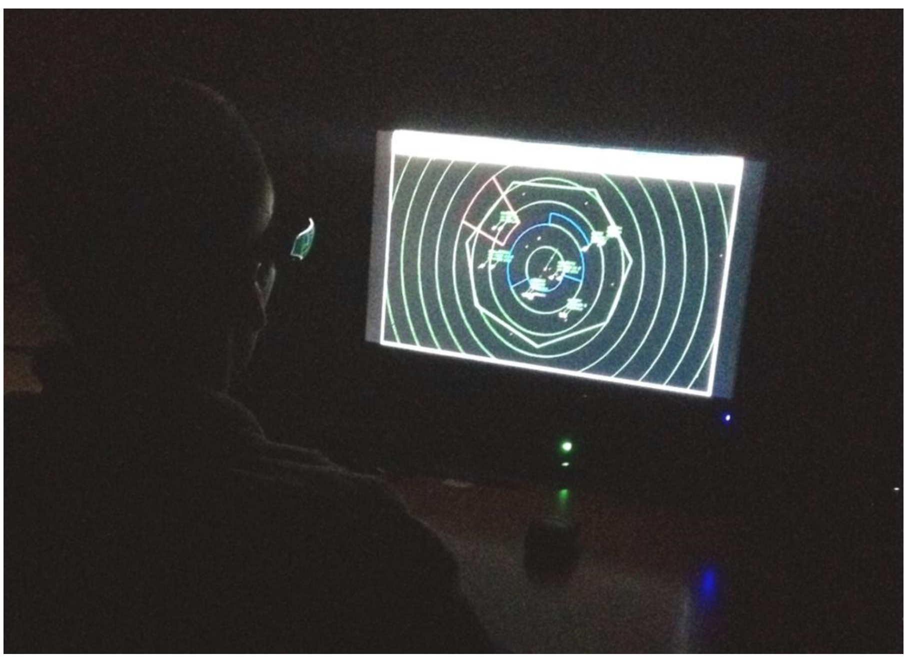


Figure 10: Experimental Workstation in Use

Participants were told in advance that the scenarios would be stopped after each scenario that they would be asked detailed questions about what they observed. Controllers were asked to actively monitor the scene and to interact through single mouse-clicks if at any point they were “unsure whether two or more aircraft may safely pass over or under one another”. This very specific phrase was chosen to preclude any inference of particular standard separation minima as each controller separates aircraft differently at with different timing; each controller’s comfort level with aircraft proximity varies greatly upon the situation at hand and innumerable cognitive factors that are ultimately based solely on the controller’s judgment.

Judgment is derived from training, experience and techniques developed thorough firsthand experience. Without a sophisticated manner in which to determine this judgment, or awareness, as SA is a inherently difficult thing to measure (Endsley, 2000), this simple phrase was employed very successfully in clarifying to each participant exactly what the single mouse-click was for and when to use it.

Therefore, when examining a controller’s performance during use of a new display, their SA must be considered both as to support it and also avoid hindering it. According to Endsley, “there is no current agreed-upon method for measuring SA”, (1995). This makes questioning experiment participants post-treatment the most effective method for gaining an understanding of the operator’s awareness (Adams, Tenney, and Pew, 1995).

Determining SA from query is best done by freezing a scenario and questioning the operator about what they saw. However, this does not actually capture their SA from that specific time which in itself may have been less clear and merely the time elapsed from the moment of observation until the time asked, the reasons, activities or other characteristics may have become clear permitting a more acceptable answer after the fact. Contrary to this, it has been shown that after the fact recall tends to contain generalized, over-summarized and simplified content that may not be an accurate assessment of situation awareness from the previous exposure, albeit immediately following, the real-time event in question (Endlsey, 2000; Nisbett & Wilson, 1977).

There are many measurement methods provided certain capabilities are present, unfortunately for the researcher the aforementioned method of pausing for questions would not be feasible in a dynamic or live-training situation making it prohibitive in the interest of flight safety as well as unrealistic. The manner in which awareness data was collected during this study will be discussed later in this paper; however, both quantitative and qualitative measures were taken.

As briefly described earlier, all participants were first administered a three minute training scenario with a two-fold purpose. The first being to ensure they would be able to see the stereoscopic disparity as intended and second, to allow them to familiarize themselves with the processes we would be using to conduct the experiment; it offered no challenge and was used only to familiarize them with the equipment and experimental process and to prevent them from being caught "cold" once actual performance measures recording began. This was found especially necessary after the pilot study revealed that subjects really didn't know what aspect of the complex actions of a controller were being focused on and thus failing to provide measurable performance for the aspects being evaluated. After the training scenario, there were brief questionnaires administered to resemble the process to be carried forward in the measured exposures. The data collected by these instruments was not retained or analyzed.

After the training scenario, the control and experimental scenarios were assigned to the participants in a predetermined randomized order. Since the participants were already volunteers randomly assigned to participate in the experiment, the control and experimental conditions were assigned in random order to the participants to support a within subjects design where each participant serves as their own control and experiment group. Participants with odd numbers had the control condition first and participants with even numbers had the experiment condition first.

The experiment employed a within subjects design to control for learning and order bias. Every subject was their own control permitting the increased statistical power afforded by a within-subjects study (Erlebacher, 1977). Keren stated, "…the exclusion of individual differences results in a higher degree of sensitivity to treatment effects" (1992). Furthermore, the exposure sequence was assigned randomly, mitigating the potential for learning bias and further strengthening the design for optimum management of participant pool and highest statistical yield.

After each eight-minute scenario, the display was blanked and a questionnaire was administered to each subject to evaluate effectiveness of the technology and their perceptions of the specific performance measures. These included a screen capture with the aircraft altitudes blanked. Participants were asked to fill in the datatags for aircraft altitudes as accurately as possible. It also contained questions about their perceptions of the technology, confidence in their answers and a place for unstructured feedback. There were no time limitations placed on any questionnaires. Please refer to Appendices C through H for actual examples of the forms, the experimental timeline with script as well as additional views of the experiment setup.

Measures

The hypotheses were tested and data collected through a post treatment questionnaire and self-reported perceptions. The only real-time feedback during the experiment was that of the mouse click inputs measuring detection and SA as mentioned previously in this chapter. Table 1 below indicates the data collection measures used.

Table 2: Data Collection Measures for Each Hypothesis

Hypotheses	Measures
H1: SA/Detection	Mouse Clicks
H2: Improve Recall Accuracy	Self-Reported Post Treatment Questionnaire Q&A/Fill-in Blanks Screen Capture
H3: Reduce Fatigue	Self-Reported Post Treatment Questionnaire Q&A and Likert Scale
H4: Reduce Workload	Self-Reported Post Treatment Questionnaire Q&A and Likert Scale
H5: Reduce Task Difficulty	Self-Reported Post Treatment Questionnaire Q&A and Likert Scale
H6: Reduce Distraction	Self-Reported Post Treatment Questionnaire Q&A and Likert Scale

Summary

This chapter presented the methodology for procuring data correlating theory and controller's efficiency through the use of an experiment. This permitted the collection and analysis of empirical data through observation of actual controllers performing realistic detection functions similar to their standard trained methods. This afforded the investigator a unique opportunity to gain insight into the potential impacts this technology may have on a number of specific controller performance measures.

IV. Analysis and Results

Overview

The following section describes the statistical analysis of the collected data. The processing was conducted with standard practices using the commercial SPSS statistical software package. A t-test was used to determine statistical differences between experimental and control display condition means for each hypothesis. Although the primary interest was in the differences between groups, since many possible independent variables (IVs) were also collected via the preliminary questionnaire, stepwise regression was also used to determine influences of other IVs. These variables were collected by self-disclosure and are as follows: gender, ATC experience in years, education level, glasses/corrective lenses wear, eye surgery, depth perception deficiency, aviation experience as pilot, SA/distraction, multitask ability, acceptance of new technology, familiarity with 3D, preference of 2D vs. 3D when given a choice for entertainment, trust of 3D views of depth, computer use as percent of daily activity, fatigue from 3D viewing, and perception of importance of the ATC job. These variables' meanings are discussed further in the following paragraphs.

These variables were considered useful pertaining to this study as indicators of performance. Distraction was a variable considered important if one said they were easily distracted. Gender was considered to analyze potential differences between men and women, but no significant influence was found. Experience in ATC was considered as a potential covariate that would be presumed to have a large influence on performance, however less experience with the technology could prevent bias against new displays. Education was considered a powerful potential indicator as one may suspect educated participants may more readily recognize potential enhancements and improvements afforded by the new display.

Use of corrective lenses, having had corrective eye surgery and self-disclosed depth perception deficiencies were considered due to the visually intense nature of the display technology being tested. Should an individual be wearing lenses that could distort or limit viewing angles or create glares could impact performance results. A deficiency in depth perception could limit one's ability to view the scenarios as intended with the correct disparity—certainly a hindrance that could impact resulting performance and serve to explain variances in performance.

Aviation experience as a pilot was considered due to the familiarity one may have as an advantage when viewing aircraft altitude changes in a 3D model based upon aircraft performance characteristics. Self distraction was considered in order to identify the participants that are easily distracted while working ATC. Individual ability to multitask was considered to identify the participants that have trouble managing multiple tasks at once or observing many things simultaneously, a factor that would also potentially limit one's performance in the experimental treatment.

Acceptance and preference was considered to evaluate participants' resistance to change or readiness to adapt to new technologies and changes in their regular workstation. Their preferred method for viewing, whether 2D or 3D when afforded a choice was also collected. Familiarity with the proposed technology was also considered in order to study its influence on participants' performance as many people had not seen a 3D movie or modern 3D television recently. Trust was considered to detect the level of confidence the participant had in the new medium, being that a low level of trust would potentially degrade the performance enhancement as the operator second-guessed displayed accuracy. Computer use was considered in order to measure time spend using computer and its influence on participants' performance.

Results

H1: The use of stereoscopic 3D digital radar displays will have a positive effect on controller situation awareness and conflict detection.

The hypothesis predicted a positive correlation between heightened SA through detection of on-screen conflicts when utilizing a stereoscopic display. The dependent variable was number of clicks indicating situation awareness reference potential conflicts. A higher number of clicks indicated a low awareness of actual conflicts. The independent variable was display condition, control was group 0, and experimental was group 1. A *t*-test was conducted with a 95% confidence interval (CI) to test for significant difference between control and experimental groups, see tables 4 & 5 below. Once significance was found, all the IVs collected from the Pre-questionnaire were considered in the stepwise regression model in order to analyze the potential influence of those factors on controllers' situation awareness and detection.

The data was assumed normally distributed as the t-test is considered robust with respect to the assumption of normality, and there was homogeneity of variance as assessed by Levene's Test for Equality of Variances. Therefore, an independent t-test was run and discovered that the control group averaged (3.40 +/- SD), a significantly higher number of clicks than the experimental group (.91 +/- 1.27) at ($t(68) = 7.991$, $p = .000$)

indicating a significant difference in SA and detection performance between the display conditions. Refer to the *t*-test and descriptive statistics tables below, Tables 3 and 4.

Table 3: H1 SA/Detection t-test Results

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper
SA	Equal variances assumed	.009	.926	7.991	68	.000	2.486	.311	1.865	3.106
	Equal variances not assumed			7.991	67.836	.000	2.486	.311	1.865	3.106

Table 4: H1 SA/Detection Descriptive Statistics

Dependent Variable: SA/Detection (clicks)

Group	Mean	Std. Deviation	N
0	3.40	1.333	35
1	.91	1.269	35
Total	2.16	1.799	70

After determining significance between the display conditions using the *t*-test, a stepwise-regression was run to determine what other variables influenced the DV. The stepwise regression model indicated a variance explained with adjusted R^2 of .613 with an additional three IVs included in the model; Fatigue, Multitask, and Experience in years at ($F(69) = 28.357$, $p = .000$). Refer to Tables 5 & 6 below for the stepwise regression model summary and coefficients.

Table 5: Model Summary for SA/Detection

Model Summary: SA/Detection			
Model	R	R Square	Adjusted R Square
1	.696	.484	.477
2	.753	.567	.554
3	.777	.604	.587
4	.797	.636	.613

Table 6: Stepwise Regression Model Coefficients for SA/Detection

Coefficients: SA/Detection						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
4	(Constant)	5.263	.889		5.919	.000
	Group	-2.486	.267	-.696	-9.296	.000
	Fatigue 3D	1.328	.515	.208	2.577	.012
	Multitask	-.519	.195	-.200	-2.666	.010
	Exper. (years)	.044	.019	.190	2.360	.021

It is presumed that the characteristic of fatigue, as a self-disclosed subjective measure, equates to higher number of clicks for those who indicated fatigue. Multitask, also a self-disclosed measure, shows fewer clicks from those who reported having a high aptitude in multitasking. The more experienced participants clicked more frequently, although not as much in the experimental treatment as in the control. This may be attributed to their conditioning to be more engaged, vigilant and exercise more positive control. It appeared that this heightened state resulted in an overly-enthusiastic reaction when faced with a very different and unfamiliar display in an attempt to not miss anything, further resulting in very pre-emptive detection of possible, yet unlikely, conflicts.

H2: The use of stereoscopic 3D digital radar displays will have a positive effect on controller recall accuracy of aircraft position.

This hypothesis predicted a positive relationship between recall accuracy and 3D stereoscopic display use. The dependent variable was recall accuracy indicating the subjects were able to accurately recall where the aircraft were in the 3D airspace, a lower result indicating poorer recall accuracy. The independent variable was display condition; control was group 0, and experimental was group 1. All the IVs collected, listed in Table 7, from the Pre-questionnaire were considered in the model in order to analyze the potential influence of those factors on controllers' recall accuracy. A *t*-test was conducted with a 95% confidence interval (CI) to test for significant difference between control and experimental groups. Once significance was found, a stepwise regression analysis was performed to detect influence of other independent variables on Recall Accuracy.

The data was assumed normally distributed as the t-test is considered robust with respect to the assumption of normality, and there was homogeneity of variance as assessed by Levene's Test for Equality of Variances. Therefore, an independent t-test was run and discovered that the control group averaged significantly higher recall accuracy of

(4.81 +/- 1.11) than the experimental group (2.73 +/- 1.15) at ($t(68) = 7.679$, p = .000) with a difference of 2.08 (95% CI, 1.54 to 2.62) indicating a significant difference in recall accuracy of aircraft position between the display conditions, however in the reverse of the expected. Refer to Tables 7 & 8 for the t-test results and descriptive statistics.

The control group showed a better retention of the information presented through evaluation of recall accuracy by way of a post-treatment questionnaire. This hypothesis is therefore not supported; however the non-intuitive finding indicates a potentially valuable insight.

Table 7: H2 Descriptive Statistics

Descriptive Statistics

Dependent Variable: Recall Acc

Group	Mean	Std. Deviation	N
0	4.811429	1.1113774	35
1	2.733333	1.1525602	35
Total	3.772381	1.5357303	70

Table 8: H2 t-test Results

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Recall Acc	Equal variances assumed	.421	.519	7.679	68	.000	2.0780952	.2706371	1.5380474	2.6181431
	Equal variances not assumed			7.679	67.910	.000	2.0780952	.2706371	1.5380344	2.6181560

After determining significance between the display conditions using the *t*-test, a stepwise-regression was run to determine what other variables influenced the DV. The stepwise regression model indicated a variance explained with adjusted R^2 of .562 with an additional two IVs included in the model; depth perception deficiency and SA/distraction at ($F(69) = 30.489$, $p = .000$). Refer to Tables 9 & 10 below for the stepwise regression model summary and coefficients.

Table 9: Model Summary for Recall Accuracy

Model Summary: Recall Accuracy

Model	R	R Square	Adjusted R Square
1	.681	.464	.457
2	.741	.548	.535
3	.762	.581	.562

Table 10: Stepwise Regression Model for Recall Accuracy

Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
3	(Constant)	3.389	.699		4.849	.000
	Group	-2.078	.243	-.681	-8.551	.000
	Depth Perception Def	-2.008	.526	-.306	-3.821	.000
	SA/Distraction	.364	.161	.181	2.263	.027

This variance between display conditions may be best explained when one considers the viewing advantages of the 3D display. Several of the participants reported having trouble recalling the exact location of the highest or lowest aircraft in the scenarios after the 3D exposure attributing their "lower priority" status to their inability to recall. This may suggest a lower awareness, but the researcher believes the contrary. A controller is trained to *not* rely on memory as much as possible and to utilize visual, audio and written cues to gather needed information upon which to make decisions. In fact, Hopkin claims that forgetting information may be just as important as remembering it in a dynamic memory situation like ATC. Since the status of each track changes so rapidly, recalling the last or last several altitudes, (or other flight characteristics), may interfere with the controller's ability to remember the current or most recent altitude (1980). This hindrance explains a valuable aspect of this result and justifies a perhaps, positive finding from an unsupported hypothesis. When a presentation allows a controller to rapidly determine priorities, or "filter through the chaff", based upon which aircraft are more likely to require separation instructions from those which are clearly operating in a safe proximity, there stands to be a cognitive benefit.

As previously disclosed in “Limitations”, the determination of SA is a difficult one. By virtue of the limited real-time feedback collected, the post-treatment questionnaires were the best method to measure this. However, the detection rates for scripted conflicts were far better in the 3D scenarios and although participants were not able to recall from memory the precise altitudes, they were able to detect that those aircraft were not in need of immediate attention and were therefore able to place focus on those aircraft that were in positions of closer proximity and that may need separation instructions. This seems to have significant workload and awareness advantages.

For the control group having a significantly better recall accuracy, this can easily be attributed to a “scan rate” or the frequency of which a controller visually “visits” each data tag on his or her screen. As earlier explained in the introduction, a controller must frequently revisit each aircraft target on their scope and evaluate the heading, speed and altitude from which they create a 3D mental model upon which they base predictions of where potential conflicts may be or will develop. When this mental model is less tasking to create, because it is already presented in such a manner visually, the controller can drastically reduce the superfluous scans and more easily “zero-in” on the areas needing their focus. Further research needs to be conducted on this interesting, non-intuitive result.

H3: The use of stereoscopic 3D digital radar displays will decrease controller fatigue.

The hypothesis predicted perceived reduction in fatigue reported by controllers when utilizing a 3D stereoscopic display. The dependent variable was a reduction in controller fatigue and the independent variable was display condition; control was group 0, and experimental was group 1. A *t*-test was conducted with a 95% confidence interval (CI) to test for a significant difference between control and experimental groups.

The data was assumed to be normally distributed as the t-test is considered robust with respect to the assumption of normality, and homogeneity of variance existed as assessed by Levene's Test for Equality of Variances. Therefore, an independent t-test was run and it was discovered no significant difference between the control and experimental groups. Control reported, (1.46 +/- .919) with the experimental group (1.37 +/- .910) at ($t(68) = .392$, $p = .696$) with a difference of .086 (95% CI, -.350 to .522) indicating no significant variance between display conditions. This hypothesis was therefore not supported. Refer to tables 11 & 12 below for t-test results and descriptive statistics.

Table 11: H3 t-test Results

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Fatigue	Equal variances assumed	.139	.710	.392	68	.696	.086	.219	-.350	.522
	Equal variances not assumed			.392	67.994	.696	.086	.219	-.350	.522

Table 12: H3 Descriptive Statistics

Dependent Variable: Fatigue

Group	Mean	Std. Deviation	N
0	1.46	.919	35
1	1.37	.910	35
Total	1.41	.909	70

Worth noting is the feedback from the participants on the brevity of the exposure not being long enough to induce fatigue. This seems to be an understandable explanation when one examines the industry standard of approximately 2.0 hours typical time in position, (Shorrock, 2007), making an eight-minute exposure far too short to induce a fatiguing effect.

H4: The use of stereoscopic 3D digital radar displays will decrease controller perceived workload

The hypothesis predicted controllers would report a reduction in perceived workload with use of the stereoscopic display. The dependent variable was controller reported perceived workload and the independent variable was display condition; control was group 0, and experimental was group 1. All the IVs collected from the Pre-questionnaire were considered in the model in order to analyze the potential influence of those factors on controllers' perceived workload.

The data was assumed normally distributed as the t-test is considered robust with respect to the assumption of normality, and there was homogeneity of variance as assessed by Levene's Test for Equality of Variances. Therefore, an independent t-test was run and discovered that the control group averaged significantly higher reported workload (4.74 +/- 1.15) than the experimental group (2.03 +/- 1.89) at ($t(68) = 8.61$, $p = .000$) with a difference of 2.714 (95% CI, 2.09 to 3.34) indicating a significant difference in controller perceived workload between the groups. Please refer to Tables 13 & 14 below for t-Test results and descriptive statistics.

Table 13: H4 t-test Results

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Workload	Equal variances assumed	.271	.604	8.616	68	.000	2.7142857	.3150318	2.0856496	3.3429219
	Equal variances not assumed			8.616	64.420	.000	2.7142857	.3150318	2.0850164	3.3435551

Table 14: H4 Descriptive Statistics

Group	Mean	Std. Deviation	N
0	4.742857	1.1521101	35
1	2.028571	1.4649978	35
Total	3.385714	1.8921277	70

After determining significance between the display conditions using the *t*-test, a stepwise-regression was run to determine what other variables influenced the DV. A model generated using a single additional covariate, SA/Distraction derived from self-disclosure from the pre-questionnaire, showed an adjusted R^2 of .598 at ($F(69) = 52.236$, $p = .000$). The SA/Distraction variable was derived from those who indicated that they do get easily distracted when performing ATC duties. Refer to Tables 15 & 16 below for the stepwise regression model summary and coefficients.

Table 15: H4 Model Summary for Workload [Perceived]

Model Summary: Workload [Perceived]			
Model	R	R Square	Adjusted R Square
1	.722	.522	.515
2	.781	.609	.598

Table 16: H4 Stepwise Regression Model for Workload [Perceived]

Coefficients: Workload [Perceived]							
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
2	(Constant)	7.835	.824		9.504	.000
	Group	-2.714	.287	-.722	-9.460	.000
	SA/Distraction	-.731	.189	-.296	-3.870	.000

The control groups reported more than double the workload than the experimental group even though the workload and traffic level were virtually identical. This finding shows potential for the technology as a workload management tool as well as decision aid.

H5: The use of stereoscopic 3D digital radar displays will decrease controller perception of task difficulty.

The hypothesis predicted controllers will have a reduced perception of task difficulty with use of a stereoscopic display. The dependent variable was controllers' reported perception of task difficulty and the independent variable was display condition; control was group 0, and experimental was group 1. All the IVs collected from the Pre-questionnaire were considered in the model in order to analyze the potential influence of those factors on controllers' perception of task difficulty.

A *t*-test was conducted with a 95% confidence interval (CI) to test for significant difference between control and experimental groups, see tables 18 & 19 below. Once significance was found, a stepwise regression analysis was performed to detect influence of other independent variables on SA/detection.

The data was assumed normally distributed as the *t*-test is considered robust with respect to the assumption of normality, and the assumption of homogeneity of variance as assessed by Levene's Test for Equality of Variances was violated. An independent *t*-test was run and it was found to be ($t(53.271) = 4.894$, $p = .000$) with a difference of 1.7 (95% CI, 1.0 to 2.40) indicating this hypothesis was supported. Please refer to Tables 17 & 18 below for t-Test results and descriptive statistics.

Table 17: H5 t-test Results

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Difficulty	Equal variances assumed	16.554	.000	4.894	68	.000	1.7000	.3474	1.0069	2.3931
	Equal variances not assumed			4.894	53.271	.000	1.7000	.3474	1.0034	2.3966

Table 18: H5 Difficulty Descriptive Statistics

Dependent Variable :Difficulty

Group	Mean	Std. Deviation	N
0	5.314	1.7950	35
1	3.614	1.0006	35
Total	4.464	1.6775	70

After determining significance between the groups using the *t*-test, a stepwise-regression was run to determine what other variables influenced the DV. three more independent variables, SA/Distraction, Aviation Experience, and Computer Use, produced a low adjusted R^2 of only .360 at ($F(69) = 10.695$, $p = .000$). The SA/Distraction variable was derived from those who indicated that they do or do not get easily distracted when performing ATC duties, Aviation experience was reported as those with pilot experience, and computer use was measured from a self-disclosed percentage of daily work performed using a computer to determine comfort and aptitude with computer technology. Very little variance between display conditions was explained using this model therefore no definitive conclusion could be drawn. Refer to Tables 19 & 20 below for the stepwise regression model summary and coefficients.

Table 19: H5 Model Summary for Difficulty

Model Summary: Difficulty				
Model		R	R Square	Adjusted R Square
	1	.510	.260	.250
	2	.556	.309	.288
	3	.596	.355	.326
	4	.630	.397	.360

Table 20: H5 Difficulty Stepwise Regression Model

Coefficients: Difficulty						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
4	(Constant)	7.076	.997		7.099	.000
	Group	-1.700	.321	-.510	-5.299	.000
	SA/Distraction	-.723	.225	-.330	-3.209	.002
	Aviation Exp	2.030	.743	.283	2.732	.008
	Computer Use	.431	.202	.217	2.130	.037

H6: The use of stereoscopic 3D digital radar displays will decrease controller distraction.

The hypothesis predicted use of a 3D stereoscopic display will reduce controller reported distraction. The dependent variable was self-reported controller perceived distraction caused by the display type with a higher number equated to increased distraction reported. The independent variable was display condition, control was group 0, and experimental was group. A *t*-test was conducted with a 95% confidence interval to test for significant difference between control and experimental groups, see tables 21 & 22 below.

The data was assumed normally distributed as the t-test is considered robust with respect to the assumption of normality, and the assumption of homogeneity of variance, as assessed by Levene's Test for Equality of Variances, was violated. An independent *t*-test was then run and it was found that the experimental group mean (2.33 +/- 1.55) was not significantly lower than the control group mean (1.96 +/- 1.33) at ($t(66.416) = -.785$, $p = .435$) with a difference of -.271 (95% CI, -.961 to .419) indicating this hypothesis was not supported. Please refer to Tables 22 & 23 below for t-Test results and descriptive statistics.

Table 21: H6 Distraction t-test Results

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Distraction	Equal variances assumed	.976	.327	-.785	68	.435	-.2714	.3459	-.9616	.4187
	Equal variances not assumed			-.785	66.416	.435	-.2714	.3459	-.9619	.4190

Table 22: H6 Distraction Descriptive Statistics

Dependent Variable: Distraction

Group	Mean	Std. Deviation	N
0	1.957	1.3305	35
1	2.229	1.5546	35
Total	2.093	1.4429	70

Summary

The findings of this experiment offer insight as to what potential benefits this technology now has in this application. The results show the potential to improve contoller detection of potential conflicts when separation minima is in jeaopardy through heightened situation awareness--a critical factor in controller performance. Further use of this technology whilst managing typical and realistic ATC tasks. There is also evidence in these results that although recall is not improved, perhaps task prioritization is, consequently, a proposed critical component of controller preformance as their responsibilities shift from that of active control to passive monitoring.

According to antecdotal data collected , 88.6% of controller's reported the 3D display was useful. 85.7% reported the 3D display improved their SA. See summary, Table 23 below, for hypotheses summation.

Table 23: Hypotheses Summary

H1: Improve SA/Detection	Click	Supported
H2: Improve recall accuracy	Self-reported	Not Supported*
H3: Reduce fatigue	Self-reported	Not supported
H4: Reduce workload	Self-reported	Supported
H5: Reduce difficulty	Self-reported	Supported
H6: Reduce distraction	Self-reported	Not supported

V. Conclusions and Recommendations

Chapter Overview

The previous four chapters relayed the research problem, investigative question, the approach and methodology to this study as well as the results and findings post-experiment. This chapter will review the findings and how they differ from the predominant literature in the field of 3D stereoscopic display use in the field of ATC. Also discussed is the potential for future work to build on this study, the potential impact of what has been discovered and the implications to today's, and possibly tomorrow's, Air Force.

Conclusions of Research

This was an exploratory study to determine if further research on stereoscopic 3D displays is warranted. The findings of this study show a very strong correlation to easing controller workload and increasing effectiveness through a variety of characteristics. The discovery of controllers' acceptance along with their resulting positive feedback and marked performance improvements in the detection of potential conflicts, increased situation awareness, and perceived reduction in workload and difficulty are strong indicators of the need for more work in the field.

Significance of Research

The findings of this study have significance in the field of human factors and performance evaluation given future air traffic controllers will likely perform their duties as passive monitors. These findings may be employed currently when testing the potential for new display and interface technologies. The results indicate the potential for controllers to monitor more aircraft without loss of situation awareness due to excessive workload, difficulty or distraction. The results also imply that controllers, with the help of this more intuitive and less mentally tasking display, may be better prepared to maintain vigilance over larger sectors for longer periods of time, as implied by the fact that perceived difficulty was reported much lower with the experimental treatment.

Safety considerations appear to be prevalent in the findings. In the interest of fatigue management, although the controllers did not report an increase or decrease in fatigue, the reported decrease in perceived difficulty, workload and increase in awareness and detection lead the researcher to believe there is fatigue mitigating potential with this concept. The increased awareness and detection of separation loss also indicate that controllers may be better equipped to maintain safe separation of aircraft thereby permitting an increase in traffic safety in the system as a whole.

Assumptions/Limitations

It was assumed from the beginning of this research endeavor that the participant pool will contain a varied mix of both novice and well-seasoned controllers with a significant breadth in experience. This was considered a strength as it allows for more insightful examination, depending on statistical analysis configurations, to determine certain implications of the technology, its employment, perceptions by, and acceptance from, the users.

It was also assumed that there was an advantage provided by the use of simulation software procured from the FAA that permitted the creation of test scenarios that were of a familiar nature to what the subjects used routinely. This also provided the researcher the ability to create and administer realistic scenarios in the way of traffic flow, potential conflicts and aircraft performance characteristics. Along with the familiarity, it was also considered that all of the participants had at least some basic instruction, if not full experience, in the art of ATC, albeit extremely fundamental in the cases of the newest of students with a mere 60 days of training.

Some limitations were noted early on in the design as well. The availability of the equipment that best represents a true workstation in size and complexity was cost prohibitive; therefore a standard, commercially available 23.5” 3D monitor with a 16:9 aspect ratio was used. This was not an optimum replacement for the standard 20” by 20” displays controllers are accustomed to, however sufficiently displayed the required view for the scenarios used. Additionally, the active shutter glasses were mandatory, and although functioned seamlessly with this experiment, would provide a hindrance in continued studies that require one to monitor adjacent 2D displays or retain any good peripheral vision as the arms were a substantial width blocking much peripheral vision.

Additionally the inability, at the time of the execution, to have dynamic real-time stereoscopic conversion meant all exposures were recordings and thereby limited the controllers to a passive monitor role. This was significant as most operators are trained and inclined to talk to the pilots and issue instructions to alter flight paths and provide the separation service, however placing current controllers in a passive role assisted in examining potential effects of this new dynamic. The only real-time interaction afforded was the singular mouse click inputs as explained in Chapter III.

Recommendations for Air Force Action

With further examination and testing of this concept, it seems future potential in mitigating a number of detrimental human performance limitations can be attained through the use of this technology in the ATC capacity. The USAF has the ability to continue this valuable research testing and to this end, potentially making our air traffic controllers better equipped to handle increased volumes of aircraft whether in a wartime or training environment. With the known value of air superiority in modern day conflict a primary AF doctrine, the ability to gain access to, possess, and maximize the use of airspace over the battlefield, the cost of failing to develop a potential force multiplying technology may be too great.

Recommendations for Future Research

It is suggested that future examination of this concept be conducted with more in-the-field experimentation using realistic scenarios and active, proficient controllers. In these trials it is recommended that the following be investigated for potential further human performance advantages:

- Real-Time dynamic scenarios allowing controller inputs for pseudo-pilot manipulation of scenario for temporal quantification of responses/inputs
- Use of stereo mirror displays that allow for flicker-free unlimited viewing angles by multiple users, light passive headgear, all in ambient lighting
- Access to live "slave" feed from active Digital Airport Surveillance Radar (DASR) to conduct real-time performance comparison 2D vs. 3D
- Applications including:
    - High Volume Undergraduate Pilot Training environments

- Simulated high-tempo mock wartime scenarios such as Nellis AFB's annual "Red Flag" wartime training exercise

- Advanced Combat Control Training simulating wartime airstrike command and control

- Remotely Piloted Aircraft en route formation cell control, break-up and re-join operations

Summary

There appear to be potential benefits to the use of stereoscopic 3D radar displays in today's air traffic control environment. The research contained in this paper is limited by time, funding and manpower, however there is more to be explored and learned in this application with favorable results in the field of human performance and human factors considerations for ATC.

Appendix A

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS UNITED STATES AIR FORCE
WASHINGTON DC

7 Jan 2012

MEMORANDUM FOR AFIT/ENV

FROM: HQ HAF/A3O-BA
1480 Air Force Pentagon
Washington, D.C.20330-1480

SUBJECT: Accessing Volunteer ATC Trainees at Keesler AFB, MS for AFIT Research

1) TSgt Russi and his research team are granted access to the USAF Air Traffic Control technical training school to conduct their research experiment with cooperation of the school's commandant, the career field manager and any volunteers willing to participate. It is understood that the research project is examining the potential of stereoscopic (3-D) digital radar display potential and textual cueing in congested communications environments. Our tech school provides the perfect environment for this study without affecting operational ATC while also allowing many AD controllers and apprentices the opportunity to participate.

2) This support is for the solicitation of volunteers at the school and is not an endorsement or expression of interest in the specific technologies being evaluated. We, as a highly technical field, understand the importance of research of technologies with potential for future use and enthusiastically support the AFIT mission of AF level research and development.

3) Please direct any questions regarding this correspondence to me at: joseph.kirk@us.af.mil.

KIRK.JOSEPH.C.102
8631681

Digitally signed by KIRK.JOSEPH.C.1028631681
DN: c=US, o=U.S. Government, ou=DoD, ou=PKI, ou=USAF, cn=KIRK.JOSEPH.C.1028631681
Date: 2012.02.07 16:46:39 -05'00'

JOSEPH C. KIRK, CMSgt, USAF
1C1 Career Field Manager

Appendix B

DEPARTMENT OF THE AIR FORCE
AIR FORCE INSTITUTE OF TECHNOLOGY
WRIGHT-PATTERSON AIR FORCE BASE OHIO

25 Jan 2012

MEMORANDUM FOR LTCOL BRENT LANGHALS

FROM: Alan R. Heminger, Ph.D.
AFIT IRB Research Reviewer
2950 Hobson Way
Wright-Patterson AFB, OH 45433-7765

SUBJECT: Approval for exemption request from human experimentation requirements (32 CFR 219, DoDD 3216.2 and AFI 40-402) for study titled "The impact on performance of stereoscopic dimensional digital radar displays and integrated automated visual text cuing on air traffic controllers".

1. Your request was based on the Code of Federal Regulations, title 32, part 219, section 101, paragraph (b) (2) (i) Information obtained is not recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects, (ii) you are not collecting information that could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects financial standing, employability, or reputation, and (4) Research, involves the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available or if the information is recorded by the investigator in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects.

2. Your study qualifies for this exemption because you are not collecting sensitive data, which could reasonably damage the subjects' financial standing, employability, or reputation. Further, the demographic data you are collecting will be maintained separately from experimental data so that a given response will not be expected to map to a specific subject.

3. This determination pertains only to the Federal, Department of Defense, and Air Force regulations that govern the use of human subjects in research. Further, if a subject's future response reasonably places them at risk of criminal or civil liability or is damaging to their financial standing, employability, or reputation, you are required to file an adverse event report with this office immediately.

ALAN HEMINGER, PH.D.
AFIT Research Reviewer

cc: Laurienne C.R.A. Santana, 1 Lt, Brazilian AF
Co-investigator
Jason G. Russi
Co-investigator
Lori Kinder, Contractor
AFIT Sponsored Programs Office

Appendix C

Experiment Scenes

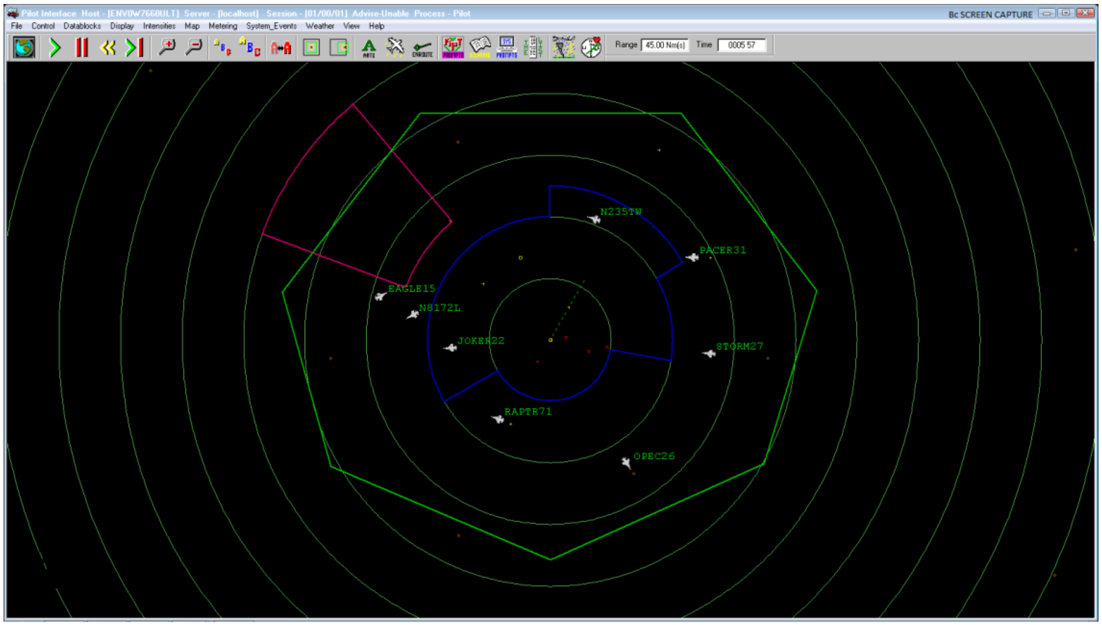


Figure 11: Initial prototype without supplementary data block information

Figure 12: Illustration of double-vision with unaided eye due to stereoscopic display

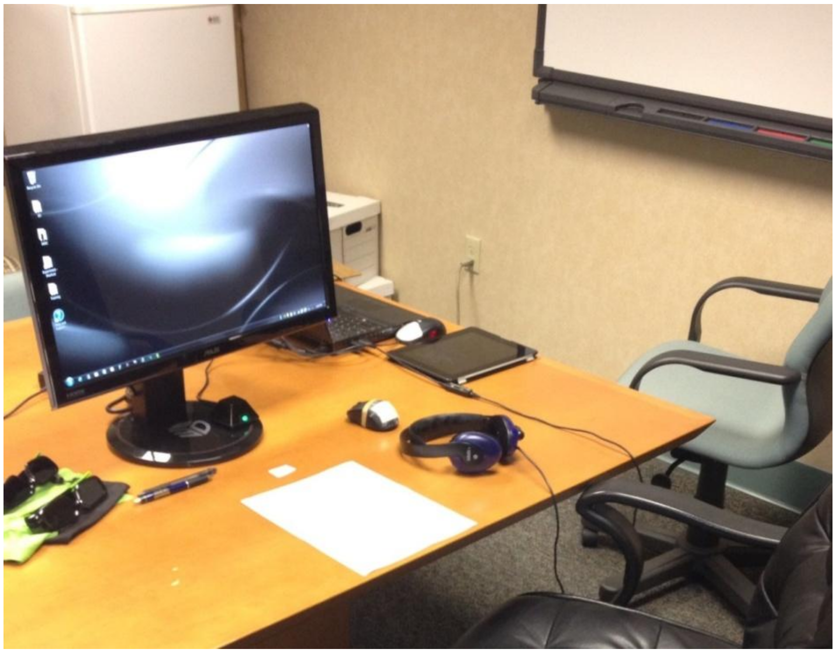


Figure 13: Experiment Setup During Data Collection

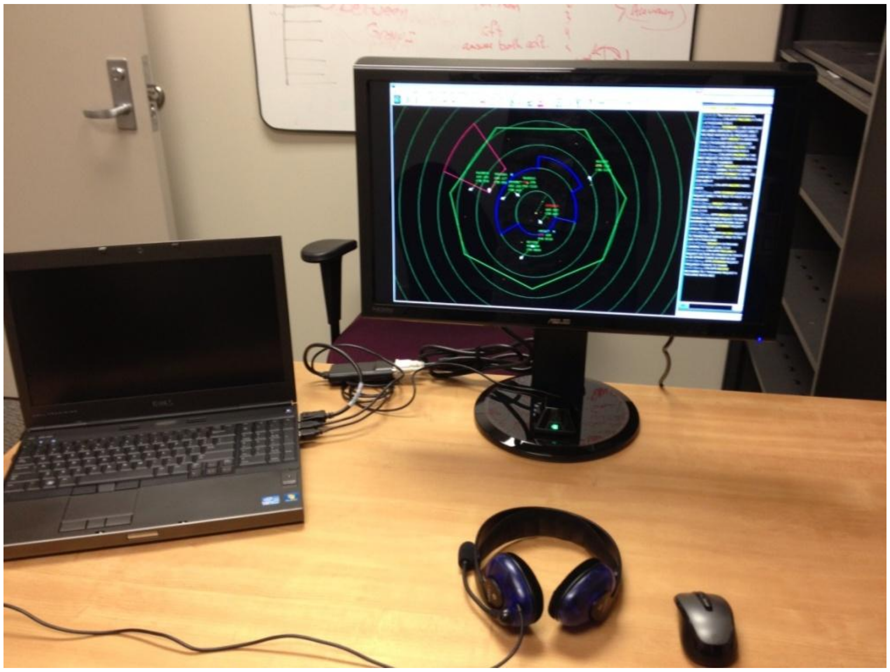


Figure 14: Experimental Workstation Layout

Appendix D

Experiment Design Timeline (Script)

TIME

T +0 Subjects arrive at experiment room 1, adjacent to room 2 where researcher 2 will initiate scenario. Consent form introduced and signed by subject (3 min)

<u>WELCOME:</u>

"I am TSgt Jason Russi and this is my colleague, Lt. Santana of the Brazilian Air Force. We would like to welcome you and thank you for your voluntary participation in this valuable research. This study will take approximately 1 hour and 20 minutes to complete. Upon completion of the study you will be given a thank-you letter recognizing your involvement in this worthwhile experiment. Before we begin, please take a moment to read through these consent forms Lt. Santana is handing you now and note your participant number written on top; remember this number as it will be used as your sole identification throughout the experiment. If you have any questions, please do not hesitate to ask either one of us at any point now or during the briefings. Of note, your responses to this experimental scenario will not be used beyond our research and will be destroyed upon completion of this study. Once you have read through the entire consent form and agree to continue to participate in this study, please sign and date the consent forms and hand them to either one of us."

Wait for participant to fill out consent form. (3 min)

T +3 Subjects read and fill in pre-experiment questionnaire. See Appendix X for full text of Pre-Experiment Questionnaire (PreQ). Questionairre will include text and dimensional display questions (5min)

"As part of this study we need to collect some demographic and background information. None of this data will be personally identifying and will in no way be connected to your name. Please take a moment to fill out this survey."

Wait for participant to fill out PreQ.. (5 min)

T+ 8 Subject is ushered into controlled scenario room/section of area. Researcher #1 reads script of process and briefs subject on the controls and familiarizes them with system that will remain the same throughout all three scenarios. This will constitute the training for the subject's interaction with system. Any questions are answered to ensure understanding of performance for subject. All scenarios will be briefed, as in what the three different types consist of and inform the subject that the order of presentation will be random, however, operation of the system will be the same. (10 mins)

TRAINING BRIEFING

"For this study you are performing duties as an n USAF Air Traffic Controller at Canyon Airport, and imaginary airfield of our design. You will be tasked with controlling several aircraft in three separate ATC scenarios. You will be expected to maintain minimum standard vertical and lateral separation between all aircraft "tracks". This performance will be evaluated on a series of measurable performance characteristics similar to the standard accepted ATC practices. You will be expected to perform the functions in these simplified scenarios allowing us to evaluate your decision making, timeliness, conflict recognition, resolution actions.

You have been invited to participate in this study due to your background in ATC and you are expected to utilize any skills or accepted separation practices as you would in a live ATC setting performing to the best of your individual ability.

If you are a student at Keesler AFB, ATC Technical School, this will in no way impact your training records or even be shared with the faculty of this school. There will be no adverse actions or retribution of any type due to your performance. Furthermore, there will be absolutely no personally identifying information (PII) collected or retained on you as an individual. Your participant number will be the only identifying information recorded for purposes of this research."

Throughout the study you will be monitored and timed as you handle conflicting aircraft tracks. The purpose of this study is to determine the impact and effectiveness of the technologies, NOT the controllers' individual performances or abilities. This is a human-computer interaction (HCI) study and therefore your responses will be compared to your own responses from the baseline of the three scenarios administered and not against others."

TRAINING BRIEFING ON MOCK CONTROL TERMINAL (MCT)

(**pendinig development as design evolves)

- Conflict detection notification by subject to be recorded. A mouse click will represent acknowledgment of a potential conflict. This may be followed with an option box posing the question of how the subject would like to handle the conflict, by turning, by altitude separation or no action and one of the three must be selected.

- To represent the intent to communicate with an aircraft, the space bar will act as a mock Push to Talk (PTT). This will allow the measurement of the attempts to communicate with the "pilots".

- Mock Control Terminal (MCT) orientation

-- headset with mic

--keyboard, mouse, and any peripherals usage

-- speaker and communication equipment (if applicable)

-- actions (inputs) for making responses; I.e. F-keys functions

-- Brief that all three variations of the scenarios will be 15 minute in duration each and that the subject shall be focusing on conflict detection and resolution in all despite varied appearances.

T +18 Researcher #1 and #2 fall back to operator's station.(This may be in the same room, depending upon space availability.) The first (control) scenario is initiated and recording of measurable begins. ALL SCENARIOS WILL BE ADMINSTERED IN A RANDOM MANNER, this will preclude any order effects that may skew data collection by bias. (15mins)

MEASURABLES (see appendix for complete list)

- Binary measurable = Yes/No

1.) Conflict detection – mouse click, subsequent question

2.) Conflict resolution attempt – question box

- Response Parameters/Quantification = Timing, quantities

1.) Time to Detection/recognition of imminent aircraft conflict

2.) Time to Resolution Attempt/decision made

3.) Time to initiate conflict resolution will be measured by initiation of control instructions to de-conflict tracks. This will allow researchers to record time of recognition and action taken

T +33	Subject scenario terminated. Subject briefed to wait in designated holding area for next scenario preparation. (2 min)
T +35	Subject is ushered into MCT again. Researcher #1 will ask subject if there are any additional questions about the experiment at this time. (3 mins)
T +38	Begin next randomly selected 15 minute scenario. (15 min)
T +53	Subject scenario terminated. Subject briefed to wait in designated holding area for next scenario preparation. (2 min)
T +55	Subject is ushered into MCT again. Researcher #1 will ask subject if there are any additional questions about the experiment at this time. (3 mins)
T +58	Begin last remaining 15 minute scenario . (15 mins)
T +73	Subject is notified of experiment termination and is ushered into holding area by Researcher #1 and is administered the Post-Experiment Questionairre (PocQ). (8 mins)

One Subject Evaluated at T +81

Simultaneously Researcher #2 resets the MCT for the next subject (3 mins) then will go administer the Pre-Experiment Questionairre (PreQ). (5 mins)

T+81	(STEP 1, Subject #2) Subject is ushered into controlled scenario room/section of area. Researcher #1 reads script of process and briefs subject on the controls and familiarizes them with system that will remain the same throughout all three scenarios. This will constitute the training for the subject's interaction with system. Any questions are answered to ensure understanding of performance for subject. All scenarios will be briefed, as in what the three different types consist of and inform the subject that the order of presentation will be random, however, operation of the system will be the same. (10 mins)

Appendix E

Informed Consent Document

For

The effect of stereoscopic dimensional digital radar displays and integrated automated visual text cuing on air traffic controller performance

AFIT/ENV, Air Force Institute of Technology, Wright-Patterson AFB OH

Principal Investigator: Lt Col Brent T. Langhals, DSN 785-3636, ext. 4352, AFIT/ENV

Brent.Langhals@afit.edu

Associate Investigators: TSgt Jason Russi, DSN 785-3636, ext. 4352, AFIT/ENV

Jason.Russi@afit.edu

1 LT Laurienne Santana (Brazilian Air Force), DSN 785-3636, ext. 4352, AFIT/ENV

Laurienne.Santana.br@afit.edu

1. **Nature and purpose:** You are being invited to take part in a research study. The information in this form is provided to help you decide whether or not to take part. Study personnel will be available to answer your questions and provide additional information. If you decide to take part in the study, you will be asked to sign this consent form. A copy of this form will be given to you. Your participation will occur at Keesler AFB, MS.

    The purpose of this study is to determine to what extent visual textual cuing and 3Dimensional air traffic representations may impact a controller's performance both in heightened situational awareness for longer durations and reduction in fatigue induced by multi-tasking, distractions, redundant transmissions and reduced mental image creation. The intent is to study what of these aspects can provide benefits to the already task saturated industry by providing increased human factors awareness.

The time requirement for each volunteer subject is anticipated to be a total of one hour over one or two visits as it need not be continuous. It is expected approximately 40 subjects will be enrolled in this study. Subjects shall be able to read and speak English, be between 18 and 60 years old, possess ATC experience or at least conceptual understanding and training with sufficient vision to perform simulated ATC tasks with a stereoscopic monitor.

2. **Experimental procedures:** If you decide to participate, the first task you will complete will be to fill out a short questionnaire to capture some demographic information. No personally identifying information will be asked of you in this questionnaire.

Next we will ask you to assume the role of an air traffic controller. You will be first presented with a common scenario to start the air traffic control activities, than you will be presented with a series of simulated air traffic situations with textual cues, and after that you will be exposed to 3D displays. Your task is to observe each simulation as different cues and presentations are added. You will be trained on 3D displays and have an overview on the station you will deal with prior to the start of the experiment. No personally identifying information will be kept. About one hour will be needed to complete this study.

Your participation in this study is voluntary. You will not lose any benefit that would normally be entitled if you do not participate or withdraw from the research. You may decide to not begin or to stop the study at any time. If you are a student, your refusal to participate will have no effect on your student status. Also, any new information discovered about the research will be provided to you. This information could affect your willingness to continue your participation and will therefore be furnished to you.

3. **Discomfort and risks:** The tasks that you will be doing have no known safety or psychological risks. Although we have tried to avoid risks, you may feel that some questions or procedures we ask you to do may be stressful, or possibly even cause you to feel fatigue. If this occurs you can stop participating immediately, however this is what we are evaluating so please feel free to express these feelings and concerns as they arise. We can give you information about individuals who may be able to help you with these problems should they go beyond the scope of the trial.

   Additionally, for this research study we may be using 3D glasses for viewing the displays. There are no known risks from using this equipment as they are commonly available commercial models.

4. **Precautions for female subjects or subjects who are or may become pregnant during the course of this study:** There are no precautions for female subjects or subjects who are or may become pregnant during the course of this study.

5. **Benefits:** You are not expected to benefit directly from participation in this research study.

6. **Compensation:** If you are active duty military you will receive your normal active duty pay.

7. <u>Alternatives: Your alternative is to choose not to participate in this study. Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. You may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled. Notify any investigator of this study to discontinue.</u>

Entitlements and confidentiality:

a. Records of your participation in this study may only be disclosed according to federal law, including the Federal Privacy Act, 5 U.S.C. 552a, and its implementing regulations and the Health Insurance Portability and Accountability Act (HIPAA), and its implementing regulations, when applicable, and the Freedom of Information Act, 5 U.S.C. Sec 522, and its implementing regulations when applicable. Your personal information will be stored in a locked cabinet in an office that is locked when not occupied. Electronic files containing your personal information will be password protected and stored only on a secure server. It is intended that the only people having access to your information will be the researchers named above, the AFRL Wright Site IRB or any other IRB involved in the review and approval of this protocol. When no longer needed for research purposes your information will be destroyed in a secure manner (shredding). Complete confidentiality cannot be promised, in particular for military personnel, whose health or fitness for duty information may be required to be reported to appropriate medical or command authorities. If such information is to be reported, you will be informed of what is being reported and the reason for the report.

b. Your entitlements to medical and dental care and/or compensation in the event of injury are governed by federal laws and regulations, and that if you desire further information you may contact the base legal office (ASC/JA, 257-6142 for Wright-Patterson AFB).

c. If an unanticipated event (medical misadventure) occurs during your participation in this study, you will be informed. If you are not competent at the time to understand the nature of the event, such information will be brought to the attention of your next of kin or other listed emergency contact.

Next of kin or emergency contact information:

Name_______________________________________ Phone#_________________

d. The decision to participate in this research is completely voluntary on your part. No one may coerce or intimidate you into participating in this program. You are participating because you want to. Lt Col Brent T. Langhals, or an associate, has adequately answered any and all questions you have about this study, your participation, and the procedures involved. Lt Col Brent T. Langhals can be reached at (937) 255-3636 ext 4352. Lt Col Brent T. Langhals, or an associate will be available to answer any questions concerning procedures throughout this study. If significant new findings develop during the course of this research, which may relate to your decision to continue participation, you will be informed. Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. You may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled. Notify one of the investigators of this study to discontinue.

e. Personal Identifiable Information to be obtained for this study includes gender, ethnicity, country of citizenship, age, and experience. Signing this document in no way alters your ability to obtain medical treatment that is not part of this study. Any Private Health Information obtained in the course of this study may be used by the investigator unless you revoke authorization to do so *in writing.* If your data is disclosed by the investigator to one of the parties listed above, those parties may pass on your data without further notification to you. Data collected in the course of this study may be withheld from you by the investigator for the duration of the study. If withheld, your data will be released at the conclusion of the study.

f. Your participation in this study will not be photographed, filmed or audio/videotaped.

YOU ARE MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. YOUR SIGNATURE INDICATES THAT YOU HAVE DECIDED TO PARTICIPATE HAVING READ THE INFORMATION PROVIDED ABOVE.

Volunteer Signature____Date_______________

Volunteer Name (printed)____

Advising Investigator Signature _____________________ Date ________________

Investigator Name (printed)____

Witness Signature ________________________ Date ________

Witness Name (printed)____

Privacy Act Statement

Authority: We are requesting disclosure of personal information.. Researchers are authorized to collect personal information on research subjects under The Privacy Act-5 USC 552a, 10 USC 55, 10 USC 8013, 32 CFR 219, 45 CFR Part 46, and EO 9397, November 1943.

Purpose: It is possible that latent risks or injuries inherent in this experiment will not be discovered until sometime in the future. The purpose of collecting this information is to aid researchers in locating you at a future date if further disclosures are appropriate.

Routine Uses: Information may be furnished to Federal, State and local agencies for any uses published by the Air Force in the Federal Register, 52 FR 16431, to include, furtherance of the research involved with this study and to provide medical care.

Disclosure: Disclosure of the requested information is voluntary. No adverse action whatsoever will be taken against you, and no privilege will be denied you based on the fact you do not disclose this information. However, your participation in this study may be impacted by a refusal to provide this information.

Appendix F

3D Pre-Experiment Screening Questionnaire

1. What is your participant number? __________

2. What is your gender? __________

3. What is your ATC experience (yrs/mos.) __________

4. What is your age? __________

5. What is your highest level of education? __________

5. Do you wear contacts or glasses? __________

If so, are you wearing them now? __________

6. Have you had corrective eye surgery? __________

7. On a scale of 1 to 5, please answer whether or not you agree with the following statements (circle one of the numbers). There is no right or wrong answer.

	Disagree				Agree
A. I can be distracted easily while working ATC.	1	2	3	4	5
B. I have trouble multitasking with many tasks.	1	2	3	4	5
C. I often ask pilots to repeat themselves when stepped on.	1	2	3	4	5
D. I think that new technologies can improve ATC.	1	2	3	4	5
E. I am familiar with 3D displays.	1	2	3	4	5
I. I convert 2D displays in a 3D mental image when working.	1	2	3	4	5
J. If cost was not an issue, I would prefer 3D entertainment.	1	2	3	4	5
L. I rely heavily on computer inputs for my duties.	1	2	3	4	5

N. I have experienced dizziness when viewing 3D movies. YES NO

O. I feel that ATC is an important job. YES NO

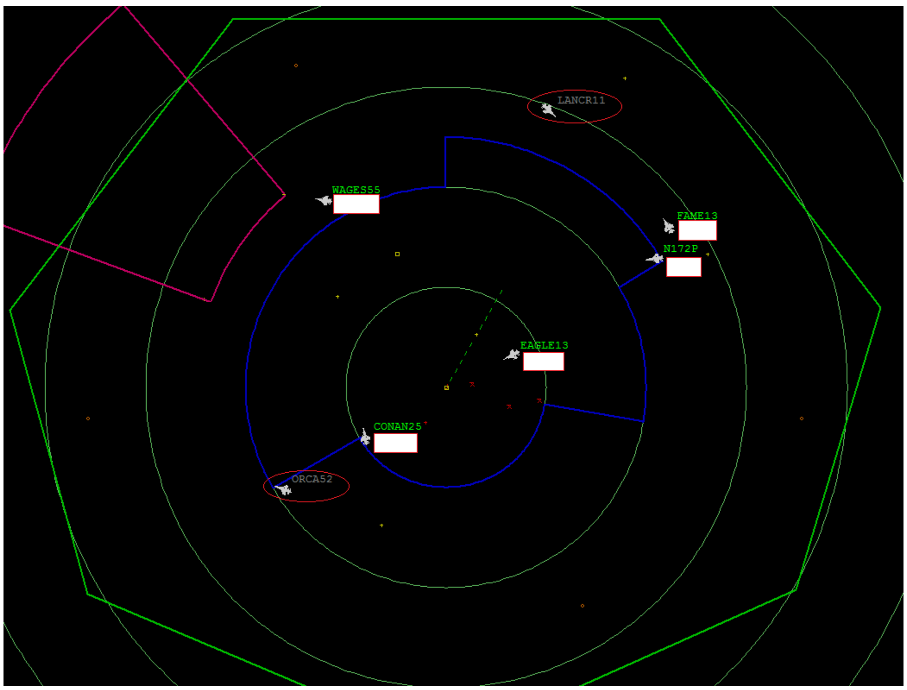
Thank-You for your honest responses and participation in this study.

Appendix G

Post-Control Questionnaire

Participant ID # _____ (*Researcher use only*:_____)

1.) Using the below screen capture from the scenario, answer the following questions;



a.) Label the aircraft 1 – 5 based on their altitudes with 1 being the closest to the surface (lowest).

b.) Did Lancer11 or Orca52 appear to be in conflict with any other aircraft? **YES NO**

c.) Which appeared to be the lowest aircraft? _____________

d.) How much vertical separation, in thousands of feet, was between Fame13 and N172P?

(1,000' 2,000' 3,000 5,000')

2). While monitoring the traffic scene, I observed the following: (circle one for each choice)

a.). The highest aircraft in the scenario was, (**Wages55** or **Conan25**) b.) Merging target procedures should have been employed (**0 or 1** or **2** or **3**) times

3). During the air traffic control simulation: (please circle one)

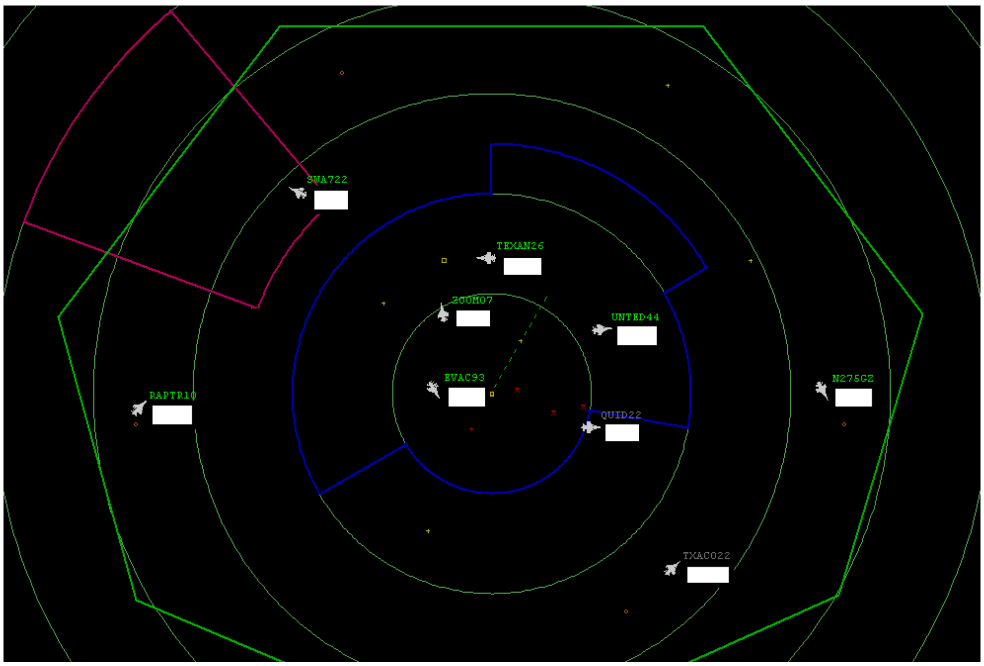
	No			**Somewhat**			**Yes**
A. I felt fatigued during the scenario.	1	2	3	4	5	6	7
B. I felt the task was over simplified.	1	2	3	4	5	6	7
C. I found it difficult to maintain concentration.	1	2	3	4	5	6	7
D. I was distracted by the aircraft with no data tags.	1	2	3	4	5	6	7
E. It was difficult to determine altitude conflicts.	1	2	3	4	5	6	7
F. I spent more time focused on overlapping targets.	1	2	3	4	5	6	7
G. I spent most time looking at altitude readouts in datatags.	1	2	3	4	5	6	7

Appendix H

Post-Experiment Questionnaire

Participant ID # _____　　　　　　　　　　　　(*Researcher use only*:_____)

1.) Using the below screen capture from the last 2 minutes of the scenario, label the aircraft in sequence 1 – 9 with 1 being the closest to the surface (lowest).



2.) While monitoring the traffic scene, I observed the following: (circle one for each choice)

A. Of the two, (**TEXAN26** or **N275GZ**) was lower.

B. The highest aircraft in the scenario was, (**EVAC93 SWA722 UNITED44/H**).

C. Merging target procedures should have been employed (**0 or 1** or **2** or **3**) times.

D. How much vertical separation, in thousands of feet, was there between EVAC93 and SWA722?
(1,000' 2,000' 3,000' 5,000')

E. How much vertical separation in thousands of feet *appeared* to be between TXACO22/H and RAPTR10? **(1,000' 2,000' 3,000' 5,000')**

3.) During the air traffic control simulation: (please circle one)

	No			**Somewhat**			**Yes**
A. I felt fatigued during the scenario.	1	2	3	4	5	6	7
B. I felt the task was over simplified.	1	2	3	4	5	6	7

C. I felt confident relying on the 3D display.	1	2	3	4	5	6	7
D. I found it difficult to maintain concentration.	1	2	3	4	5	6	7
E. The tasks seemed too difficult.	1	2	3	4	5	6	7
G. 3D enhanced display improved [SA].	1	2	3	4	5	6	7
H. I would like to work with 3D more.	1	2	3	4	5	6	7
I. I found it difficult to use the 3D display.	1	2	3	4	5	6	7
J. I found this 3D display to be useful.	1	2	3	4	5	6	7
K. I used appearance of height over data block info.	1	2	3	4	5	6	7
L. 3D display was easier to determine altitude than data text.	1	2	3	4	5	6	7
M. I found the text to be easier to read even when overlapped.	1	2	3	4	5	6	7
N. I feel the 3D display made scanning for conflicts easier.	1	2	3	4	5	6	7

6). Often controllers choose to employ strategies to maintain awareness, make decisions and improve performance. Did you find the 3D display to be conducive to your style of scanning?

Yes No If yes, please briefly describe how it impacted your style or method:

____

____

7). Please indicate whether you felt altitudes were made more or less apparent with the 3D view. W*hy?*

____

____

Bibliography

Adams, M. J., Tenney, Y. J., & Pew, R. W. (1995). Situation awareness and the cognitive management of complex systems. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 37*(1), 85-104.

Alm, T., & Lif, P. (2007). The value of spatial cues in 3D air traffic displays. *International Journal of Aviation Psychology, 17*(2), 109-129. doi: 10.1080/10508410701328490

Bourgois, M., Cooper, M., Duong, V., Hjalmarsson, J., Lange, M. & Ynnerman, A. (2005). Interactive and Immersive 3D Visualization for ATC. In: USA/Europe Seminar on Air Traffic Management Research and Development,2005 (pp. 303). Washinton, DC, USA: FAA

Chau, D., McGinnis, B., Talandis, J., Leigh, J., Peterka, T., Knoll, A., . . . Jellinek, J. (2012). A simultaneous 2D/3D autostereo workstation. Paper presented at the *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, , 8288* 89.

Carlson, J. R. (1995). *Channel Expansion Theory: A Dynamic View of Media and Information Richness Perceptions,*

Carlson, J. R., & Zmud, R. W. (1999). Channel expansion theory and the experiential nature of media richness perceptions. *Academy of Management Journal, 42*(2), 153-170. doi: 10.2307/257090

Dang, N. T., Le, H. H., Tavanti, M., & Duong, V. (2003). A multidisciplinary framework for empirical analysis of the applicability of 3D stereoscopic in air traffic control. Paper presented at the *Computational Intelligence in Robotics and Automation, 2003. Proceedings. 2003 IEEE International Symposium on, , 2* 811-816.

Dang-Nguyen, T., Le-Hong, H., & Tavanti, M. (2003). Empirical analysis of the applicability of 3D stereoscopic in air traffic control. Paper presented at the *Intelligent Transportation Systems, 2003. Proceedings. 2003 IEEE, , 1* 693-697.

Endsley, M. R. (2000). Theoretical underpinnings of situation awareness: A critical review. *Situation Awareness Analysis and Measurement, ,* 3-32.

EP, G. (1971). Fatigue and stress in air traffic controllers. *Ergonomics, 14*(1), 159.

Erzberger, H. (2004). Transforming the NAS: The next generation air traffic control system. Paper presented at the *Proceedings of the 24th Int. Congress of the Aeronautical Sciences (ICAS),*

Federal Aviation Administration. (2001). FAA order 7110.65 M, chapter 2, section 3. *Available Online at: http://www.faa.gov/regulations_policies/orders_notices/index.cfm/go/document.information/documentID/1019803*

Federal Aviation Administration. (2012). *FAA aerospace forecast fiscal years 2012-2032* (1st ed.). Washington, D.C.: FAA.

Galster, S. M., Duley, J. A., Masalonis, A. J., & Parasuraman, R. (2001). Air traffic controller performance and workload under mature free flight: Conflict detection and resolution of aircraft self-separation. *International Journal of Aviation Psychology, 11*(1), 71-93. Retrieved from http://ezproxy.libraries.wright.edu:2048/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=4792841&site=ehost-live

Gronlund, S. D., United States. Office of Aviation Medicine, Civil Aeromedical Institute, & University of Oklahoma. Dept. of Psychology. (1997). *The role of memory in air traffic control*. Washington, D.C.; Springfield, Va.: U.S. Dept. of Transportation, Federal Aviation Administration, Office of Aviation Medicine; Available to the public through the National Technical Information Service. Retrieved from http://purl.access.gpo.gov/GPO/LPS84902

Green, D. M., & Swets, J. A. (1966). *Signal detection theory and psychophysics* Wiley New York.

Hopkin, V. D. (1980). The measurement of the air traffic controller. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 22*(5), 547-560. doi: 10.1177/001872088002200504

Hopkin, V. D. (1995). *Human factors in air traffic control* CRC.

Jones, D. G., & Endsley, M. R. (1996). Sources of situation awareness errors in aviation. *Aviation, Space, and Environmental Medicine,* Luna, T. D. (1997). Air traffic controller shiftwork: What are the implications for aviation safety? A review. *Aviation, Space, and Environmental Medicine, 68*(1), 69.

M.R. Endsley. & D.G. Jones. (2012). *Designing for Situation Awareness.* (2nd ed., p. 123). Boca Raton FL: CRC Press

Magazu III, D.Exploiting the automatic dependent surveillance-broadcast system via false target injection.

Marsa, L. (2009). Wing and prayer. *Discover, 30*(8), 58-65. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=aph&AN=43977857&site=ehost-live

McIntire, J. P., Havig, P. R., & Geiselman, E. E. (2012). What is 3D good for? A review of human performance on stereoscopic 3D displays. Paper presented at the *Proc. of SPIE Vol, , 8383* 83830X-1.

Means, B., Mumaw, R., Roth, C., Schalger, M., McWilliams, E., Gagne, E., Rice, V., Rosenthal, D., &Heon, S. (1988). ATC training analysis study: Design of the next-generation ATC training system (OPM Work Order No. 342-036). Richmond, VA: HumRRO International.

Metzger, U., & Parasuraman, R. (2006). Effects of automated conflict cuing and traffic density on air traffic controller performance and visual attention in a datalink environment. *International Journal of Aviation Psychology, 16*(4), 343-362. doi: 10.1207/s15327108ijap1604_1

Metzger, U., & Parasuraman, R. (Winter 2001). The role of the air traffic controller in future air traffic management: An empirical study of active control versus passive monitoring. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 43*(4), 519-528. doi: 10.1518/001872001775870421

Mikkola, Maija, Satu Jumisko-Pyykko, Dominik Strohmeier, Atanas Boev, and Atanas Gotchev. "Stereoscopic depth cues outperform monocular ones on autosereoscopic display." IEEE Journal of Selected topics in signal processing 6 (2012): 698-709.

National Transportation Safety Board. 2007. Attempted Takeoff From Wrong Runway, Comair Flight 5191, Bombardier CL-600-2B19, N431CA, Lexington, Kentucky, August 27, 2006. Aircraft Accident Report NTSB/AAR-07/05. Washington, DC.

Nisbett, R. E., & Wilson, T. D. (1977). Telling more than we can know: Verbal reports on mental processes. *Psychological Review; Psychological Review, 84*(3), 231.

Parker, E., & Wallis, P. (1948). Three-dimensional cathode-ray tube displays. *Electrical Engineers-Part III: Radio and Communication Engineering, Journal of the Institution of, 95*(37), 371-387.

Persiani, F., & Liverani, A. (2000). Semi-immersive synthetic environment for cooperative air traffic control. Paper presented at the *Proceedings of 22nd International Congress of Aeronautical Sciences, Harrogate, UK, , 27* 08-01.

Peterson, S., Axholt, M., & Ellis, S. R. (2008). Managing visual clutter: A generalized technique for label segregation using stereoscopic disparity. Paper presented at the *Virtual Reality Conference, 2008. VR'08. IEEE,* 169-176.

Prevot, T., Homola, J., & Mercer, J. (2008). Human-in-the-loop evaluation of ground-based automated separation assurance for NEXTGEN. Paper presented at the *Congress of International Council of the Aeronautical Sciences Anchorage, Anchorage, AK,*

Rantanen, E. M., McCarley, J. S., & Xu, X. (2004). Time delays in air traffic control communication loop: Effect on controller performance and workload. *International Journal of Aviation Psychology, 14*(4), 369-394. doi: 10.1207/s15327108ijap1404_3

Rantanen, E. M., & Nunes, A. (2005). Hierarchical conflict detection in air traffic control. *International Journal of Aviation Psychology, 15*(4), 339-362. doi: 10.1207/s15327108ijap1504_3

Redding, R.E. (1992). *Analysis of operational errors and workload in air traffic control*. Proceedingsof the 36th Annual Meeting of the Human Factors Society, 1321-1325

Salas, E., & Maurino, D. (Eds.). (2010). *Human factors in aviation* (1st ed.). Burlington, MA: Elsevier.

Sarter, N. B., Woods, D. D., & Billings, C. E. (1997). Automation surprises. *Handbook of Human Factors and Ergonomics, 2*, 1926-1943

Shorrock, S. T., (2007). Errors of perception in air traffic control. *Safety Science, 45*(8), 890-904. doi: 10.1016/j.ssci.2006.08.018

Shorrock, S. T., & Isaac, A. (2010). Mental imagery in air traffic control. *International Journal of Aviation Psychology, 20*(4), 309-324. doi: 10.1080/10508414.2010.487008

Steven T., S. (2007). Errors of perception in air traffic control. *Safety Science, 45*(8), 890-904. doi: 10.1016/j.ssci.2006.08.018

Tavanti, M., & Cooper, M. (2009). Looking for the 3d picture: The spatio-temporal realm of student controllers. *Human Centered Design,* , 1070-1079.

Thomas, L. C., & Wickens, C. D. (2006). Display dimensionality, conflict geometry, and time pressure effects on conflict detection and resolution performance using cockpit displays of traffic information. *International Journal of Aviation Psychology, 16*(3), 321-342. doi: 10.1207/s15327108ijap1603_5

Wickens, C. D. (2002). Situation awareness and workload in aviation. *Current Directions in Psychological Science (Wiley-Blackwell), 11*(4), 128-133. Retrieved from http://ezproxy.libraries.wright.edu:2048/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=6982022&site=ehost-live

McCallie, D. L. (2011). *Exploring potential ADS-B vulnerabilities in the FAA's NextGen air trasnportation system.* (Unpublished MASTERS). Air Force Institute of Technology, Dayton, OH.

Magazu III, D.Exploiting the automatic dependent surveillance-broadcast system via false target injection.

Parasuraman, R., Molloy, R., & Singh, I. L. (1993). Performance consequences of automation-induced ‘complacency'. *The International Journal of Aviation Psychology*, *3*(1), 1-23.

Xing, J., & Manning, C. A. (2005). *Complexity and Automation Displays of Air Traffic Control: Literature Review and Analysis,*

Vita

TSgt Jason G. Russi graduated from Aurora High School in Aurora Ohio in 1996. He entered active duty as an Airman Basic in 2000 and began his career as an air traffic controller the same year. TSgt Russi served 12 years in different control facilities in Oklahoma, S. Korea, England, Kosovo, and Texas.

He earned his undergraduate degree in Professional Aeronautics with Embry-Riddle Aeronautical University while on active duty and was accepted as an "Enlisted-to-AFIT" student in 2011. His follow-on assignment is to remain at Wright-Patterson AFB, OH as an air traffic controller.

REPORT DOCUMENTATION PAGE					*Form Approved* *OMB No. 0704–0188*
The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704–0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202–4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE (DD–MM–YYYY) 21-03-2013			2. REPORT TYPE Master's Thesis		3. DATES COVERED *(From — To)* AUG 2011 – MAR 2013
4. TITLE AND SUBTITLE Effects of Stereoscopic 3D Digital Radar Displays on Air Traffic Controller Performance					5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Russi, Jason George, Technical Sergeant, USAF					5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Air Force Institute of Technology Graduate School of Engineering and Management (AFIT/ENY) 2950 Hobson Way WPAFB OH 45433-7765					8. PERFORMING ORGANIZATION REPORT NUMBER AFIT-ENV-13-M-24
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) INTENTIONALLY LEFT BLANK					10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION / AVAILABILITY STATEMENT DISTRIBUTION STATEMENT A: APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED					
13. SUPPLEMENTARY NOTES This material is declared a work of the U.S. Government and is not subject to copyright protection in the United States.					
14. ABSTRACT Air traffic controllers are responsible for directing air traffic based upon decisions made from traffic activity depicted on 2Dimensional (2D) radar displays. Controllers must identify aircraft and detect potential conflicts while simultaneously developing and executing plans of action to ensure safe separation is maintained. With a nearly 100% increase in traffic expected within the next decade (FAA, 2012a), controllers' abilities to rapidly interpret spacing and maintain awareness for longer durations with increased workload will become increasingly imperative to safety. The current display design spatially depicts an aircraft's position relative to the controller's airspace as well as speed, altitude, and direction in textual form which requires deciphering and arithmetic to determine vertical separation. Since vertical separation is as imperative to flight safety as lateral separation, affording the controller an intuitive design for determining spacing without mental model creation is critical to reducing controller workload, and increasing awareness and efficiency. To examine this potential, a stereoscopic radar workstation simulator was developed and field-tested with 35 USAF controllers. It presented a view similar to traditional radar displays, (i.e. top-down), however, it depicted altitude through the use of 3D stereoscopic disparity, permitting vertical separation to be visually represented.					
15. SUBJECT TERMS ATC, 3D DISPLAY, SITUATION AWARENNESS, ATC HUMAN PERFORMANCE					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Brent Langhals, LtCol, PhD, USAF
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U	UU	113	19b. TELEPHONE NUMBER (Include Area Code) (937)255-3636, ext 4352 brent.langhals@afit.edu